2000

The growth and distribution of the green alga Cladophora at Presqu'ile Provincial Park: Implications for management (Ontario)

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0-612-52217-2

The Growth and Distribution of the green alga *Cladophora* at Presqu'ile Provincial Park: Implications for Management.

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Wilfrid Laurier University, 2000

THESIS
Submitted to the Department of Geography and Environmental Studies in partial fulfilment of the requirements for the Masters of Environmental Studies degree
Wilfrid Laurier University
2000

Abstract

The Green alga genus *Cladophora* is one of the most abundant kinds of algae worldwide, found in both freshwater and marine environments. It prefers nutrient-rich waters and requires a rocky substrate and water movement for growth. When water temperatures reach 22 to 26 _C, the alga dies and washes into shore in large mats. Dead *Cladophora* produces a terrible odour, reduces property values and can alter the taste of drinking water.

At Presqu'ile Provincial Park, maximum *Cladophora* sloughing occurred July 22 1999, the same time as peak summer park visitation begins. This results in the fouling of the Park's beaches and campground areas. The result is a loss of revenue as some visitors avoid the Park during the summer months. The deposition of the algae on the beaches has become an issue for two reasons. It now occurs later in the season than observed in the 1980s and there are more algae being deposited around the Park than in the early 1990s.

The primary reason for the increase in *Cladophora* at Presqu'ile is increased water clarity in Lake Ontario in the nearshore zone. Zebra mussels (*Dreissena polymorpha*) filter particles out of the water while feeding and light now penetrates deeper, allowing *Cladophora* access to new areas for growth. There is not an increase in *Cladophora* biomass per square metre compared to 1982 and 1983, but there is now more suitable habitat on which growth is occurring.

The algae is also benefitting from an increase in bird biomass in the offshore colony. Although the total number of nests has decreased, Ring-billed Gulls (Larus delawarensis) have been replaced by the larger Double-crested Cormorant (Phalacrocorax auritus). The birds ensure that the local *Cladophora* is not phosphorus limited, but growth may be limited by other nutrients at Presqu'ile.

Acknowledgments

The list of people who helped me arrive at where I am today is a long one. There are so many of you who have always been there for me, ready to offer support and encouragement. For those of you not mentioned in this list, I am truly sorry.

To start, I would like to thank my family and friends. You guys are the ones who motivated me when I was procrastinating, and took me out when I needed a break. Thanks to Matt and Cynthia DeJong for being there. To Willy Van Arragon for support and to Ellwood Harris, I've never forgotten who delivered me to WLU for that first meeting. Special thanks to John DeJong. You've always been there for me in so many ways, I hope to be able to repay the favour someday.

Thanks to the Brubacher bunch for Sunday nights and to my adopted family, Bill and May Wilson for Maybags, shaped wood, friendship and food. To my friends Mark Raycroft and Bill Hodgkinson, thanks for your patience as I have been finishing this project. I hope to resume a calmer life soon! To Mike Gurr and Phil Careless, sorry about "bird or die", next year...... To Darrell Ford, I appreciated the help, but I didn't like that school any way. This thesis is in memory of my friend Andy McMurtry, I wish I could have shared it with you.

Thanks to my supervisor, Dr. Mary-Lou Byrne. Mary-Lou allowed me to run with this study, all the while steering it from a distance. Thanks for chatting, lunches and laughter. Thanks also to my pseudo-supervisor Todd Howell. I wouldn't like to think of what this study would look like without your input, data and lab facilities.

I would like to thank the many people at school who have helped me on my way. Cathy Conrad, who directed me to WLU; Virginia Wagg, one of the best secretaries on the planet; Pam Schaus, map Queen; Bill Taylor, Stephanie Guildford and Jane Almond, UW biology; Alex McLean, the tolerant tech; the WLU Grad Studies department, for being understanding. Thanks also to my Committee of Hamish Duthie, Mike English, Houston Sanderson for their constructive criticism.

Thanks to the Staff of Presqu'ile Provincial Park, especially my Field Assistants Rosalie Leonard, Patricia Delesroch and Ben Postance. Thanks to Brian Brown, Jack Horton, Lisa Hughson and Jay Reynolds for keeping track of algae collection on the beach. Thanks to Tom Mates, Park Superintendent- for not making me choose what I wanted to do! Thanks to Eve Rusaw, the other best secretary on the planet and my reality check. Thanks also to Don Tyerman, for criticism, ideas and friendship, and introducing the world to "DeJong time".

Finally, I would like to thank the most important person in my life, Tricia Chapman. You have supported me through it all and helped me achieve this goal, I'll never forget that. I look forward to starting on the next part of our lives together.

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Chapter 1

Introduction

The Green alga *Cladophora* is one of the most abundant genera of freshwater alga worldwide (Pentecost, 1984). It can be found in rivers, small ponds and large water bodies such as the Great Lakes, providing there is moving water (Whitton, 1970). *Cladophora* is the dominant attached plant in the lower Great Lakes and was referred to as one of the major biological problems in Lake Ontario in the late 1960s and early 1970s (Bellis and McLarty, 1967; Casey et al., 1973). According to Pentecost (1984), the most abundant species, *Cladophora glomerata*, can be identified by the green mats in which it grows affixed to the substrate, its long strands that grow up to one metre in length, and its well branched filaments (Fig. 1.1).

Cladophora can be an environmental problem because accumulations of algae can have a significant impact on humans settled near a water body. When algae die and wash into shore it is unsightly and has a terrible odour (Neil and Owen, 1964; Mantai, 1987). It can change the taste of drinking water and block water intakes from rivers and lakes (Narumaiani et al., 1997; Poston and Gamet, 1964). Algal mats have a negative effect on shoreline property values and can result in reduced Park visitation to beaches (Ormerod, 1970; Mates, 1999).

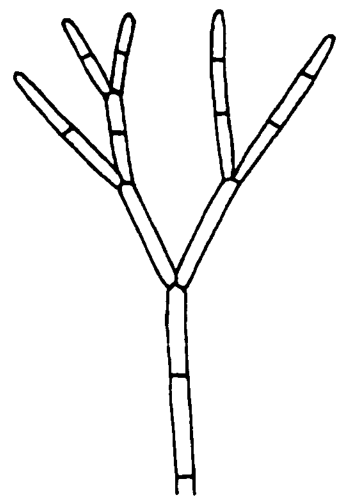


Figure 1.1
An illustration of the branched filaments of Cladophora Glomerata (Pentecost, 1984:185).

Cladophora can also have a detrimental impact on animals and plants living in a water body. Algae mats destroy potential shoreline feeding and spawning grounds for many fish species, including whitefish (Christie, 1973). Algal blooms result in shade intolerant plant species being shaded out and eliminated (Stoermer et al, 1985). It is widely believed that most algae, and *Cladophora* in particular, played a relatively minor role in aquatic communities before the activities of humans led to nutrient enrichment (Whitton, 1970).

1.1 Purpose of the study

The purpose of this study is to describe *Cladophora* growth and deposition at Presqu'ile Provincial Park, Ontario, Canada. Presqu'ile's beaches are important to the local tourist industry and are visited by almost 250,000 people per year. When beaches are fouled by algae, the park suffers a loss of revenue as visitors no longer desire to use the facilities (Mates, 1999). The beaches are also an important staging area for migrating shorebirds.

The goals of this study are as follows:

- To monitor *Cladophora* growth at two sites in Lake Ontario offshore of Presqu'ile Provincial Park over the duration of the growing season to determine the timing of peak biomass.
- To monitor Lake Ontario water chemistry over the study period to determine if the *Cladophora* growing in the area is nutrient limited.
- To determine if present *Cladophora* growth and deposition in the area are typical or significantly more than historical levels.
- To examine the relationship between *Cladophora*, zebra mussels and aquatic invertebrates.
- To critically examine the beach management techniques used by Presqu'ile Provincial Park.

1.2 Previous studies

There is a large body of literature on the topic of *Cladophora*. The majority of the North American publications were from the 1960s to the mid 1980s. These generally relate to the eutrophication and nutrient enrichment of the Great Lakes over this time period and the subsequent algal growth. In 1982, the Journal of Great Lakes Research devoted an entire issue to the study of filamentous algae (IAGLR, 1982).

There is also literature on *Cladophora* from places such as Australia (Birch and Gabrienson, 1984) and the United Kingdom (Planas et al., 1996). These articles discuss *Cladophora* in rivers, streams and water bodies of all sizes.

At Presqu'ile, *Cladophora* biomass was sampled in 1972, 1982 and 1983 and the results were presented in Painter and Kamaitis (1987). These results act as a baseline for this study and will be referred to in depth in the discussion (Chapter 5). No other studies on *Cladophora* growth at Presqu'ile were found.

1.3 Thesis layout

This study is divided into six chapters. The first is a general introduction to *Cladophora* and why the study took place. The second chapter is the background and provides information on the preferred growing conditions of *Cladophora*, the suitability of Lake Ontario for *Cladophora* growth, water chemistry, zebra mussels, aquatic invertebrates and a description of the study area. The third chapter describes the methodology and techniques used to obtain the results in this study. The fourth chapter presents the results and the fifth chapter is the discussion and summary. Chapter 6 presents some recommendations for beach management at Presqu'ile Provincial Park and proposes directions for future research.

Chapter 2
Background

2.1 Introduction

The purpose of this chapter is to provide the necessary background information to put the study into a local context. It will begin with a description of the preferred growing conditions of *Cladophora* and the suitability of Lake Ontario for *Cladophora* growth. It will then examine present and historical growth conditions of the area and the processes that influence *Cladophora* growth. An introduction to Lake Ontario water chemistry, zebra mussels and aquatic invertebrate communities in the nearshore zone will then be presented. The chapter will conclude with a description of the study area, the history of *Cladophora* at Presqu'ile Provincial Park and the suitability of Presqu'ile for *Cladophora* growth.

2.2 The preferred growing conditions of *Cladophora*

As mentioned in chapter 1, the green algae *Cladophora* is one of the most abundant kinds of freshwater algae worldwide (Pentecost, 1984). *Cladophora glomerata* growth begins in the spring when light intensity increases and water temperatures exceed 10°C (Whitton, 1970). Preferential growth historically occurs in the nearshore zone at depths under 10 metres, but growth can occur at depths up to 50 metres (Painter, 1998;

Kindle, 1915). Maximum growth occurs in early summer between June and July and there is a second smaller bloom at the end of the summer between August and September (Bellis and McLarty, 1967). Individual pieces of *Cladophora* have been recorded at lengths up to just under 4 m long under optimal conditions, but tend to be under 1 m (Pentecost, 1984; Rochester Gas and Electric Corp., 1977).

Optimal *Cladophora* growth occurs at temperatures between 18 and 20°C (Great Lakes Laboratory, 1970). *Cladophora* health declines as water temperatures exceed 24°C and death occurs at 26°C (Benda, 1976; Thurman and Kuehne, 1952). *Cladophora* growth occurs only in waters with a pH between 7 and 9, with optimal photosynthesis at 8.2 (Bellis, 1967; Mantai, 1987).

Cladophora requires a rocky substrate or bedrock for the algal growth and over-wintering (Thurman and Kuehne, 1952).*Cladophora* also requires water movement for optimal growth and increased rates of flow allow it to make more efficient use of nutrients (Casey et al., 1973). It is most productive where currents keep nutrient levels high by importing fresh nutrient rich water, preventing local deficiencies (Whitton, 1970). It is known to respond very quickly to increases in these nutrients, particularly phosphorus (Sly, 1991).

Optimal *Cladophora* growth occurs in eutrophic and mesotrophic water bodies rich in phosphorus (Pentecost, 1984). Phosphorus availability, more than any other nutrient, limits the growth of aquatic plants (Gerloff and Fitzgerald, 1976; Hartig and Gannon, 1986). According to the Environment Canada (1970), phosphorus is the primary limiting factor to *Cladophora* growth. Phosphorus levels are also the primary *Cladophora* growth factor that humans influence (Environment Canada, 1970). Other nutrients such as carbon are available to lakes from a number of sources. These including carbon dioxide from the atmosphere, bicarbonate from the substrate and carbon from natural organic matter (Environment Canada, 1970). Nitrogen is available from several sources, including fertilizers, manure, organic waste and precipitation (Environment Canada, 1970).

2.3 The suitability of Lake Ontario for *Cladophora* growth

Lake Ontario is located in eastern North America and is the terminal lake in the Great Lakes system. It receives water from Lake Erie through the Niagara River and runoff from the lake basin. Lake Ontario is 309 km long, has a mean width of 60 km and an average depth of 86 metres (Fig. 2.1).

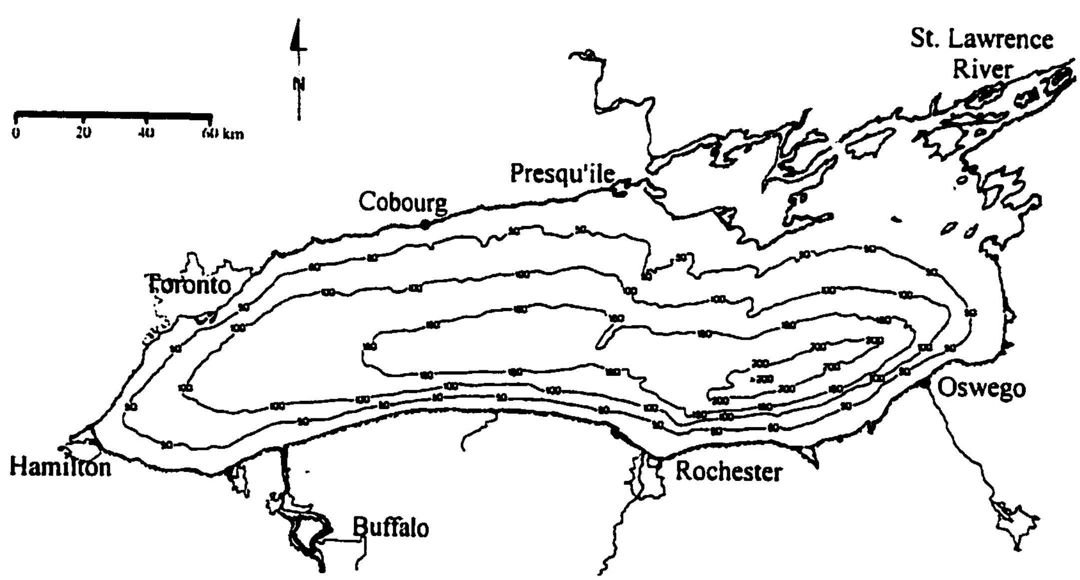


Figure 2.1.
Lake Ontario with depth contours in metres (Dobson, 1984).

The conditions of the lake make it an ideal location for *Cladophora* growth. The present and historical growth conditions will be discussed in the following sections.

2.3.1 Present growth conditions

As previously mentioned, *Cladophora* growth is dependent upon several factors and portions of Lake Ontario's north shore presently meet all growth requirements (International Lake Erie Water Pollution Board and the International Lake Ontario-St. Lawrence River Water Pollution Board, 1969). Human development has raised nutrient levels and structures such as harbours, shoreline protection devices and water intakes provide suitable habitat (Bellis and McLarty, 1967).

Optimal *Cladophora* growth occurs in water between 18 and 20°C, within the range of Lake Ontario temperatures between July and September (Fig. 2.2). These optimal temperatures occur in the top 10 metres of the lake, where *Cladophora* growth is the most abundant because of light penetration (Bellis and McLarty, 1967; Painter, 1998). Water clarity has increased over the past 10 years because of the arrival of Zebra Mussels, which will be discussed in section 2.6. Lake Ontario surface water temperature can be influenced locally by effluents into the lake from industry and power generating stations. This can result in *Cladophora* growth earlier in the season and an earlier summer die off if the temperature exceeds 26°C (Benda, 1976).

Nutrients such as phosphorus can also be locally enriched in large water bodies such as Lake Ontario. The lake is presently oligotrophic offshore, but increased *Cladophora* growth is common at point source nutrient sources such as river mouths, farms and water treatment facilities in the nearshore zone where the water is eutrophic

(Goulden et al, 1970). Studies in Lake Erie on point source nutrient loading, have shown a 90% increase in *Cladophora* cover in under 2 months with the addition of 0.35 kg of supplemental phosphorus per day (Neil and Jackson, 1982).

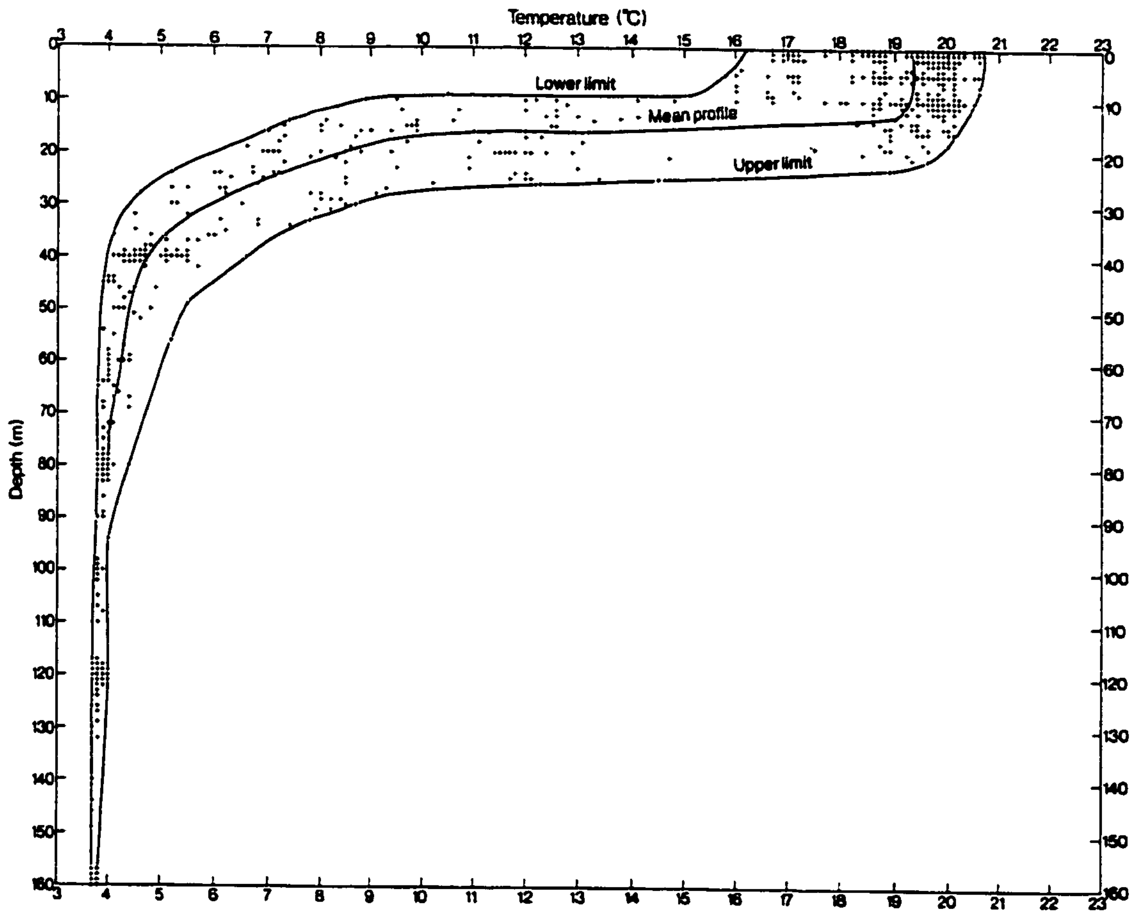


Figure 2.2.
Temperature versus depth at 32 stations in Lake Ontario, September 5 to 11, 1972 (Dobson, 1984).

Water pH is also critical for algal growth. Lake Ontario's pH is presently within the acceptable range for *Cladophora*, between the range of 7 and 9 throughout the water column (Fig. 2.3).

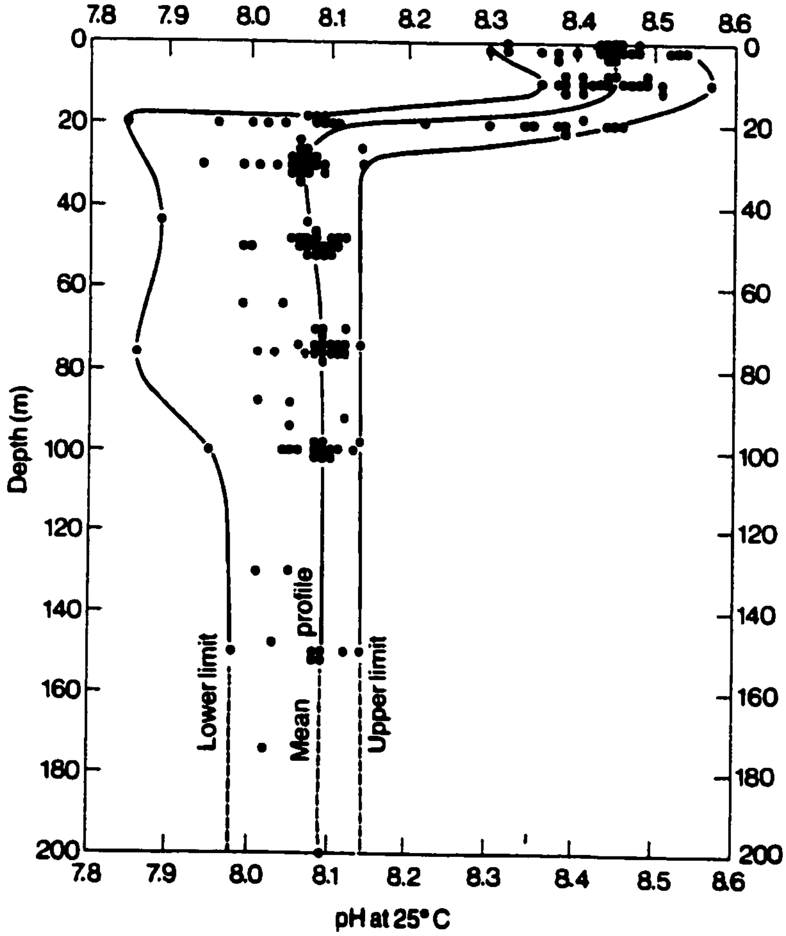


Figure 2.3.
The pH measured at 25°C versus depth at several Lake Ontario sites, September 13 to 16, 1966 (Dobson, 1984).

On the north shore of Lake Ontario, 75% of the substrate is suitable for *Cladophora* growth (Rukavina, 1970; Whitton, 1970). According to Whitton (1970), 55% of the lake bottom between Whitby and Wellington is composed of glacial sediment which will support moderate *Cladophora* growth, while 20% is bedrock, which supports dense *Cladophora* growth (Fig 2.4). Sand is not a suitable substrate for *Cladophora* as it is too easily shifted by wave and sub-aerial processes (Thurman and Kuehne, 1952).

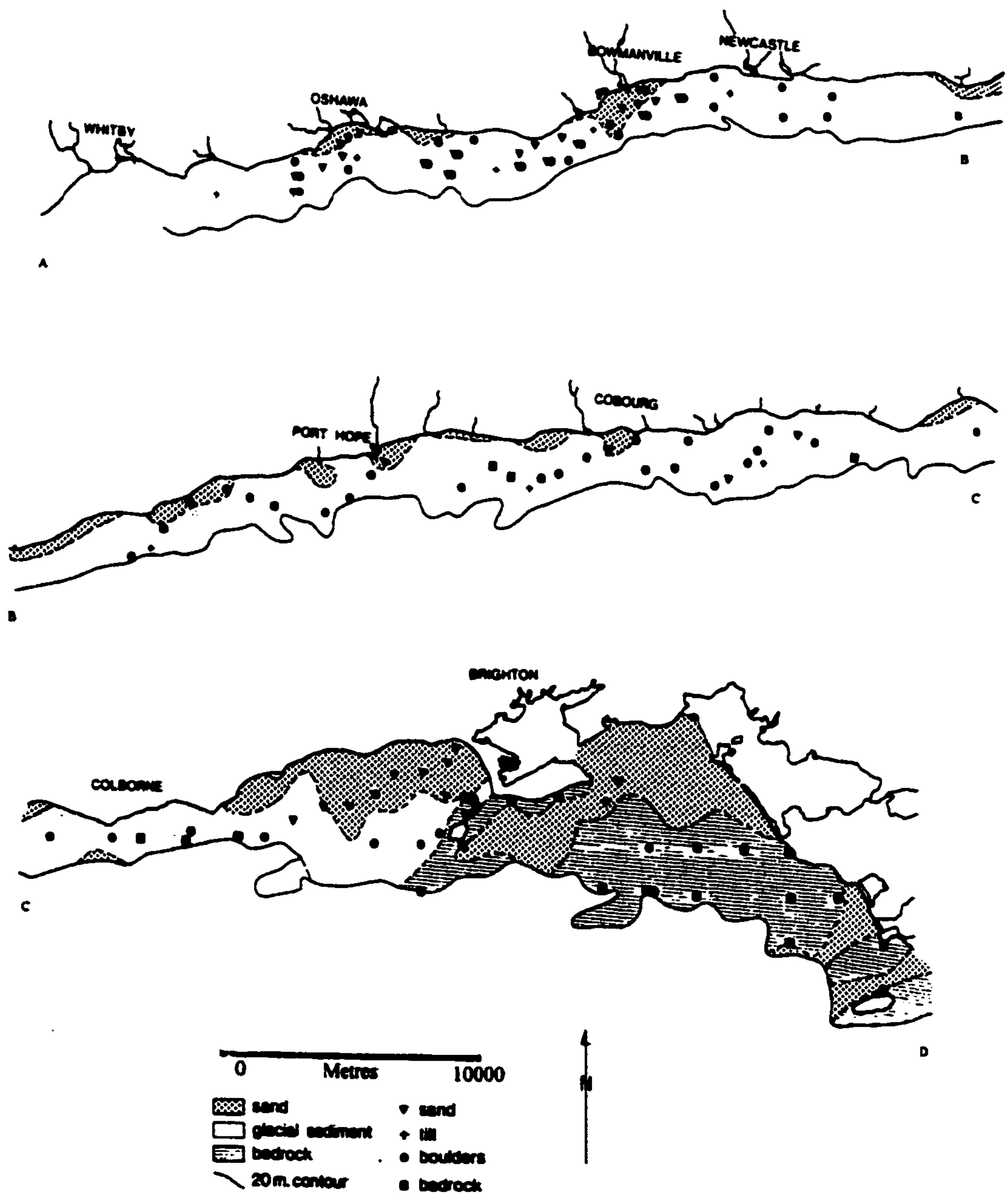


Figure 2.4.
The distribution of bottom types in the nearshore zone of Lake Ontario (Rukavina, 1970).

2.3.2 Historical growth conditions

Since human settlement began in the mid-1700s, the Lake Ontario ecosystem has been modified. According to Sly (1991:62), "Lake Ontario and its watershed have been subjected to almost every type of human-induced stress that can be imposed on a lake." This has resulted in species composition being altered at all scales, from macrophytes and benthic invertebrates to fish species (Crowder and Bristow, 1986; Hurley, 1986; Johnson and McNeil, 1986; Stoermer et al., 1985). These changes are the result of the dumping of pollutants, the use of the lake as a sewer and local temperature increases in nearshore areas. The result of the dumping has been the eutrophication of Lake Ontario and this, along with the warming has increased production by primary producers such as algae (Sly, 1991).

Lakes with high nutrient levels that are highly productive are defined as eutrophic. Lakes sometimes become eutrophic as they get older and as nutrients are added (Thain and Hickman, 1995). The addition of nutrients by humans resulting in a rise of net primary production is called cultural eutrophication and can cause algal blooms (Environment Canada, 1970). The nutrients added usually take the form of phosphorus or nitrogen and cause algal blooms that lead to the deoxygenation of the water through consequent bacterial activity. Phosphorus was believed to be the "critical factor controlling eutrophication" (Environment Canada, 1970:2). The largest single change in Lake Ontario over the past few centuries has been nutrient availability (Sly, 1991). Since commercial farming and large-scale settlement began in the Lake Ontario basin, phosphorus levels have been on the rise.

Lake Ontario is the final lake in the Great Lakes basin and 34% of its phosphate input comes from Lake Erie via the Niagara River (Environment Canada, 1970). The Lake has experienced significant changes in algal species composition and abundance since human settlement occurred (Sly, 1991). A core taken by Stoermer et al. (1985) from the floor of Lake Ontario showed the following general trends between 1780 and 1975. Between 1780 and 1815 there was a small increase in the algal population. This is a product of early settlement and the clearance of land which resulted in increased sediment inputs into rivers. From 1831 to 1845 there was a slight decrease in the Lake Ontario algal population as silica became a limiting factor to algal growth. Between 1860 and 1900 there were large phosphorus inputs into Lake Ontario as commercial farming started along its shores, catchment basins and tributaries. From 1900 to 1945 major changes began to occur to Lake Ontario flora. These changes included increasing algae production and local extinctions of less tolerant plant species as they were out competed for space and nutrients by the fast growing algae. Between 1945 and 1975 large-scale phosphorus enrichment occurred. The effects of eutrophication became apparent and this resulted in increased *Cladophora* production lake-wide. The increased phosphorus levels, especially from 1900 to 1975, can also be attributed to the chemicals introduced into surface waters by the increasing population living in the Lake Ontario basin (Fig. 2.5).

In 1972, the International Joint Commission (IJC) began to regulate effluents being discharged into the lakes by municipal wastewater treatment plants (Hartig and Gannon, 1986). A 7.6-billion-dollar municipal wastewater treatment plant improvement project was started and the phosphate content of treatment effluents was given a limit of no more than 1.0 mg/L in the Great Lakes (Hartig and Gannon, 1986).

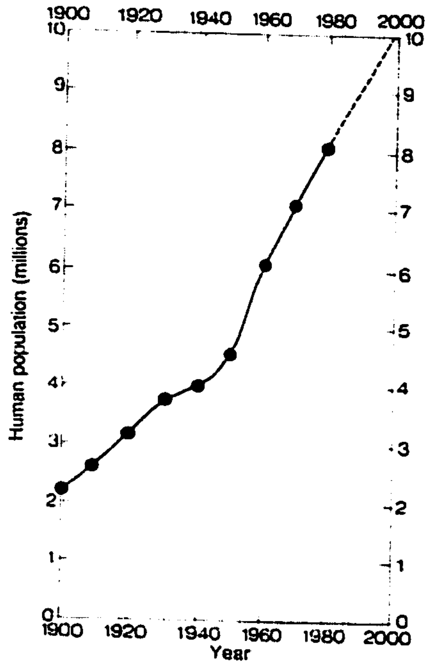


Figure 2.5.
Lake Ontario human population from 1900-2000, including the Lake Ontario basin and the city of Buffalo (Dobson, 1984).

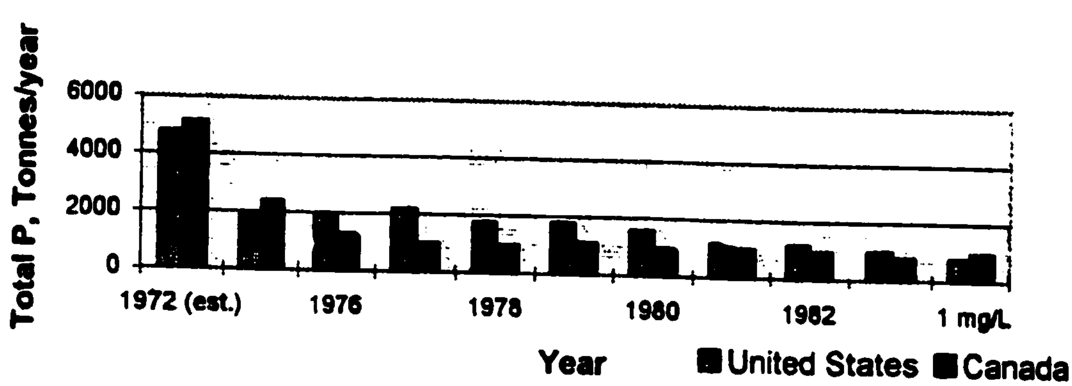
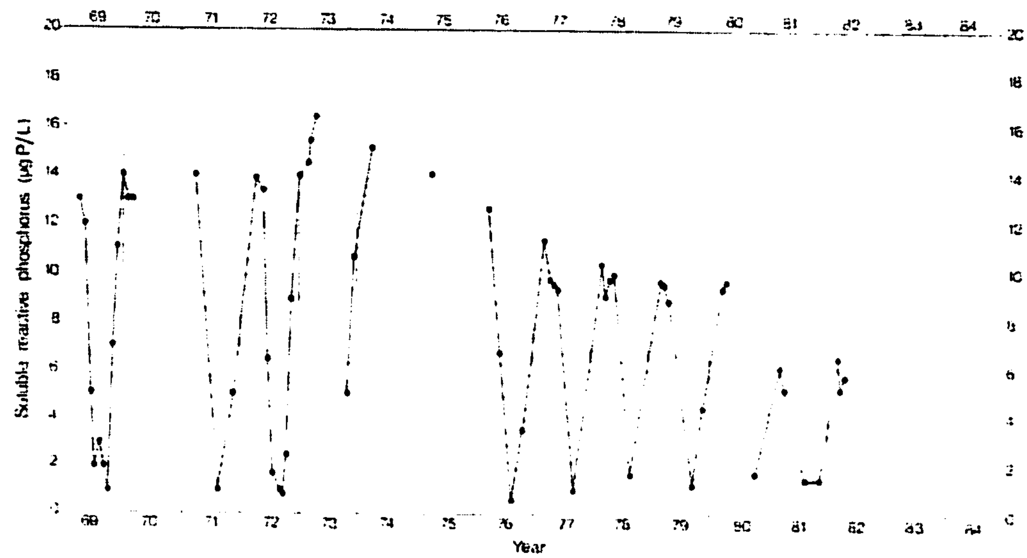


Figure 2.6
Declines in the municipal phosphorus loads to Lake Ontario between 1972 and 1983. The 1972 figure is an estimate (Based on Hartig and Gannon, 1986).

Phosphate detergents were banned and these changes resulted in Lake Ontario phosphorus loads decreasing immediately (Fig. 2.6). The declining levels of phosphates in the lake occurred along all gradients. Mid-lake concentrations declined from 30.6 um/L-1 in 1973 to 12.8 um/L-1 in 1982 (Stevens and Neilson, 1987). The declining trend could also be seen in water samples taken from the surface and at the bottom of the lake over the 1969 to 1982 study period (Fig. 2.7). The impacts of the reduced phosphate loading are more apparent in the epilimnion than the hypolimnion. This is because of the role that sediments play in storing phosphates and their slow release rates.

The declining phosphorus levels between 1972 and 1983 resulted in a decrease in *Cladophora* biomass and tissue phosphorus concentrations at several Lake Ontario sites (Fig 2.8). The reduced phosphate levels became a growth limiting factor and resulted in lake wide reductions in algal biomass (Hartig and Gannon, 1986). The large declines in *Cladophora* have resulted in another change to species composition in Lake Ontario (Stoermer et al, 1985). The green algae species no longer dominate the other plant and algae species living there.

a) 

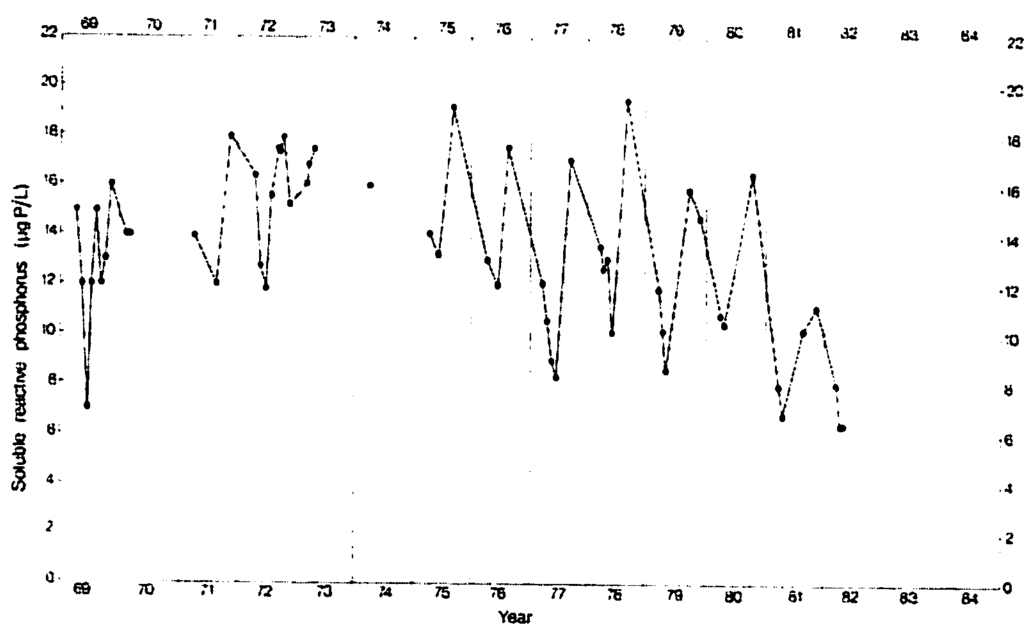
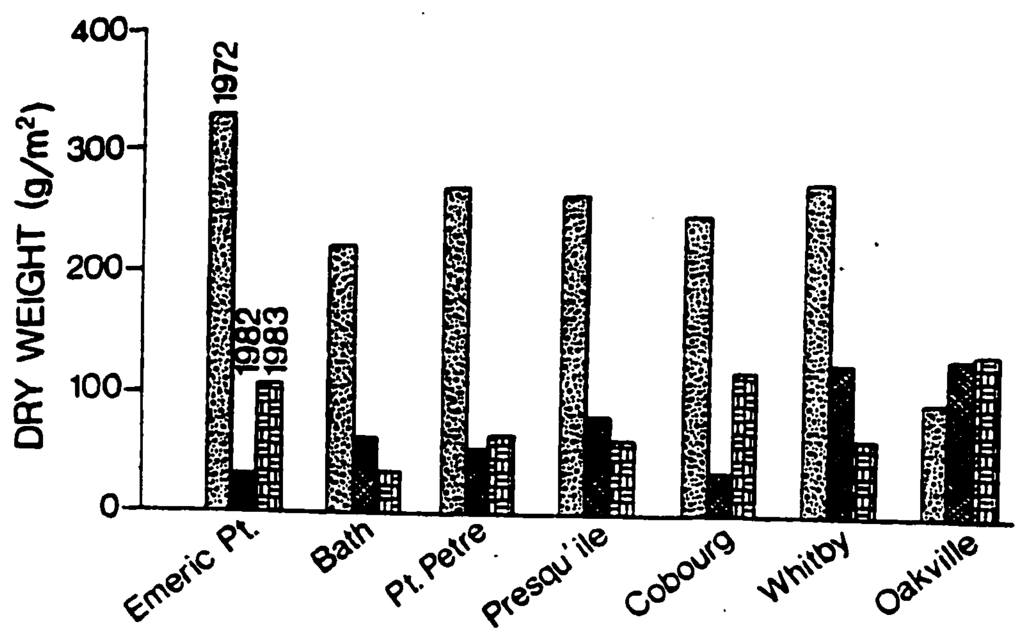
b) 

Figure 2.7.

a) Soluble reactive phosphorus in near surface waters of Lake Ontario at several sites between 1969 and 1982.

b) Soluble reactive phosphorus in near bottom waters of Lake Ontario at several sites between 1969 and 1982. (Dobson, 1984).



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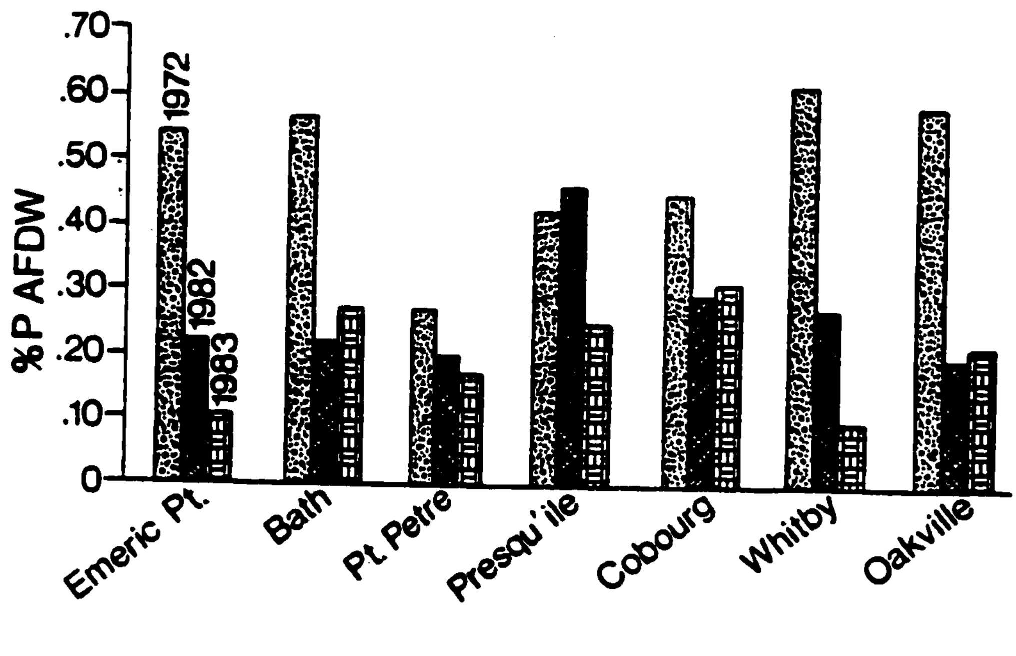


b)

Figure 2.8.
a) *Cladophora* biomass in 1972, 1982 and 1983 at each sampling station.
b) *Cladophora* tissue phosphorus levels in 1972, 1982 and 1983 at each sampling station. (Painter and Kamaitis, 1987).

2.4 Processes that influence *Cladophora* growth

Several processes influence *Cladophora* growth, including nutrient storage in sediments, lake circulation and nitrogen and phosphorus ratios. Intense studies on nitrogen and phosphorus levels in Lake Ontario began in 1964, when increased nutrient levels resulted in large algal blooms (Stevens and Neilson, 1987). General nutrient cycling models were developed that attempt to quantify and predict the interactions between the nutrients and the water, the nutrients and the sediment, and the water and the sediment (Fig 2.9).

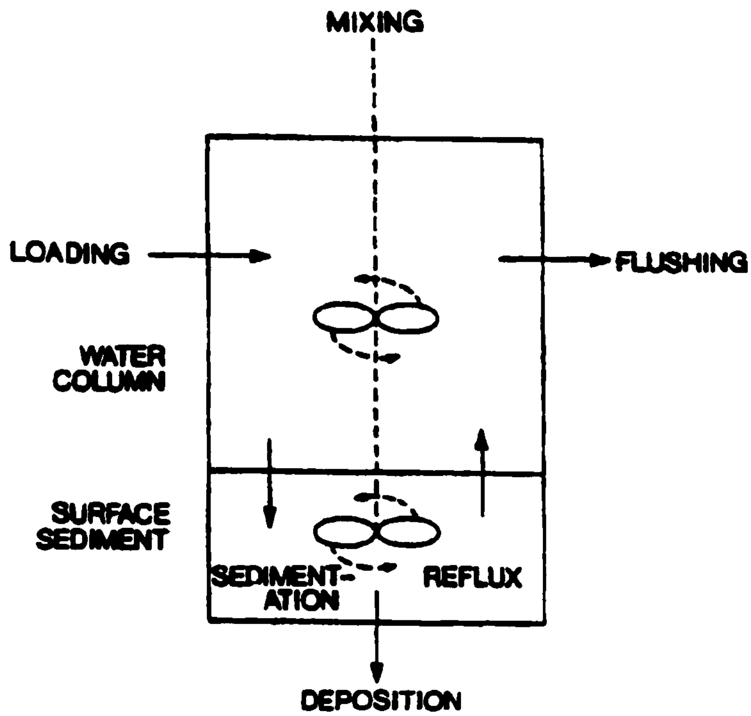


Figure 2.9.
The concept of a two-component whole lake phosphorus model (Minns, 1986a).

An important physical process that influences the storage of nutrients, and phosphorus in particular, is sediment grain size distribution. The surface area of sediment particles influences their absorption rate, with the finer sizes having a higher absorption potential (Hwang et al., 1976). Phosphorus stored in sediments is released over time if concentrations of p in the water are below that of the sediment. The release rate results in a lag time in measurable reductions after decreasing inputs of phosphorus into a water body (Stevens and Neilson, 1987). The release rate of nutrients from sediments is critical, and can be more important to water quality than the quantity of phosphorus available (Young and DePinto, 1982). Often, fresh sediments are deposited over nutrient-rich sediments and remove the stored phosphorus from the system until the are uncovered (Environment Canada, 1970). Sediments and their storage processes play a very important role in the quantity of phosphorus available for *Cladophora* growth. Sediments play a vital role in phosphorus storage and act as a reservoir that can maintain high *Cladophora* growth after point source nutrient additions have been stopped (Minns, 1986a).

Lake circulation is the second physical process that can influence *Cladophora* growth. At the beginning of the *Cladophora* growing season in May, phosphates are not as concentrated at any point source or layer of the lake and are well mixed throughout the water column (Scavia and Bennett, 1980). This changes in the late spring and early summer when thermal stratification begins to occur and inputs tend to be confined to the epilimnion (Neilson and Stevens, 1987). This top layer can become phosphorus limited in mid-summer because of the nutrient uptake by plants and storage in the sediments (Neilson and Stevens, 1987). By September, the phosphorus levels rise again in relation to the mid-summer *Cladophora* die-off. A large gradient from point source phosphorus concentrations to sites in the middle of the lake often appears. The phosphorus concentrations can be from 25 to 30 um/L-1 at point sources to between 10 and 12 um/L-1 in the open water (Neilson and Stevens, 1987). Lake circulation and thermal stratification play a major role in the amount of nutrients that are available for *Cladophora* growth in the spring and summer.

The third important process influencing *Cladophora* growth is a chemical one: changing nitrogen to phosphorus (N:P) ratios. Nitrogen limits *Cladophora* growth only in highly eutrophic water bodies (Nicholls and Carney, 1986). However, as phosphate levels have declined since 1972, nitrogen levels have increased (Stevens and Neilson, 1987; Hartig and Gannon, 1986). This relationship can be clearly seen in Figure 2.10.

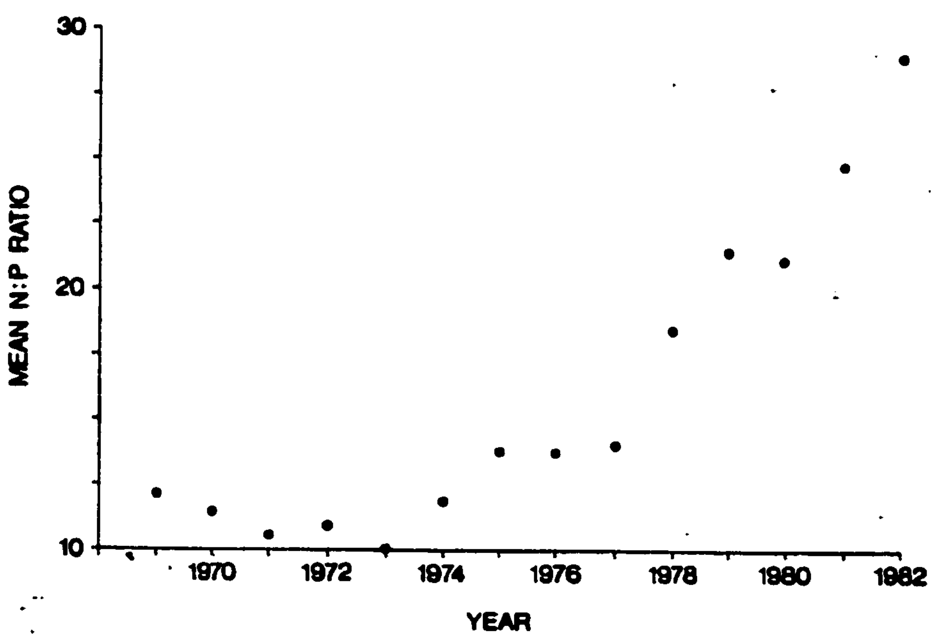


Figure 2.10.
Changes in the N:P ratios between 1968 and 1982 (Stevens and Neilson, 1987).

N:P ratios have increased from 10:1 in 1969 to 32:1 in 1982. Once the N:P ratio is above 20:1, nitrogen no longer limits *Cladophora* growth (Stevens and Neilson, 1987). The increase of nitrogen in Lake Ontario is thought to be primarily due to atmospheric deposition and agricultural inputs, particularly in the Spring (Hartig and Gannon, 1986).

Atmospheric deposition is also a major source for phosphates in lakes (Dillon et al., 1991). Atmospheric deposition has always been an active source for phosphates in Lake Ontario, but the high inputs from detergents before 1972 made this component appear to be insignificant. The changing N:P ratios indicate that in the offshore zone, Lake Ontario is becoming increasingly oligotrophic and a less hospitable home to the green algae *Cladophora*.

2.5 Water Chemistry at Cobourg, Ontario 1980-1999

Cobourg is located on the north shore of Lake Ontario, 40 kilometres west of Presqu'ile Provincial Park. The Ontario Ministry of the Environment and Energy (MoEE) has collected and analyzed samples from the raw water intake at the Cobourg water treatment plant since 1980. The tests include chloride, chlorophyll a and b, nitrate (NO3), nitrite (NO2), ammonia (NH3), total Kjeldahl nitrogen, dissolved organic and inorganic carbon, reactive silicate and total phosphorus (TP).

The TP data indicate a peak of 0.182 mg/L in July 1995 and a minimum of 0.004 mg/L in September 1999 (Fig. 2.11). The general trend is declining TP levels with occasional large peaks that are associated with runoff events such as snow melt and rain storms.

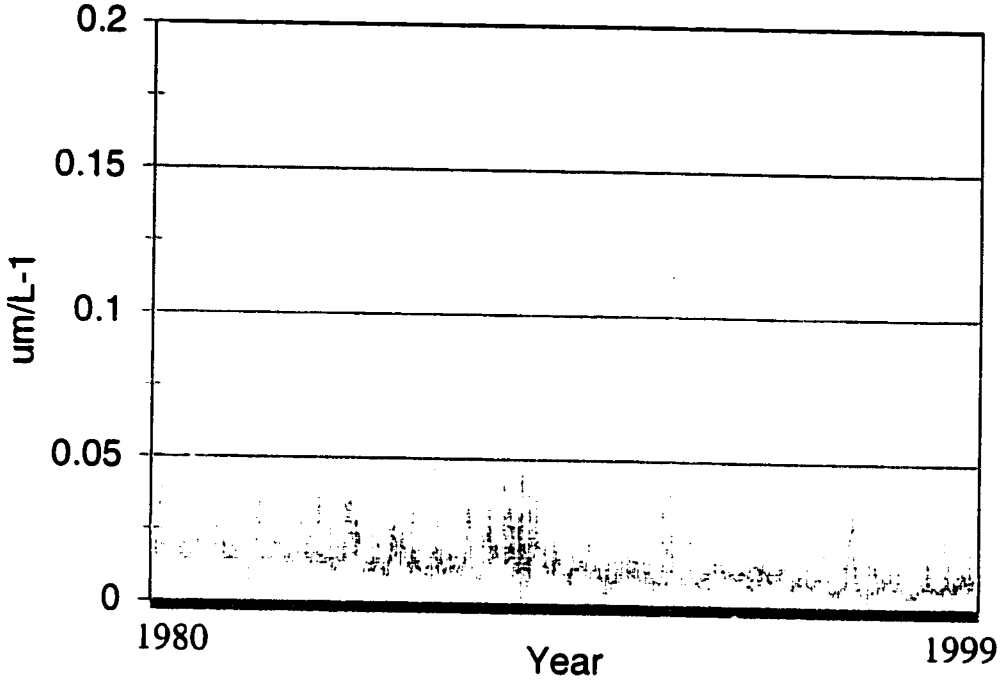


Figure 2.11.
Total phosphorus levels of water collected weekly at the Cobourg water treatment plant intake from January 1980 to October 1999. Peaks can be attributed to runoff events and snow melt. (MoEE, 1999).

Unlike the TP data, on average nitrate (NO3) levels at Cobourg have been stable since 1980. The pattern seen in the graph is because of seasonal variations and peaks are likely associated with runoff events (Fig. 2.12). Water chemistry data from Cobourg indicate that Chloride, Chlorophyll a and b, nitrate (NO3), nitrite (NO2), ammonia (NH3), total Kjeldahl nitrogen, dissolved organic and inorganic carbon, reactive silicate and TP levels are all stable or declining since 1980 (MoEE, 1999). According to these data, Lake Ontario in the Cobourg area has become a less suitable home for *Cladophora* since 1980.

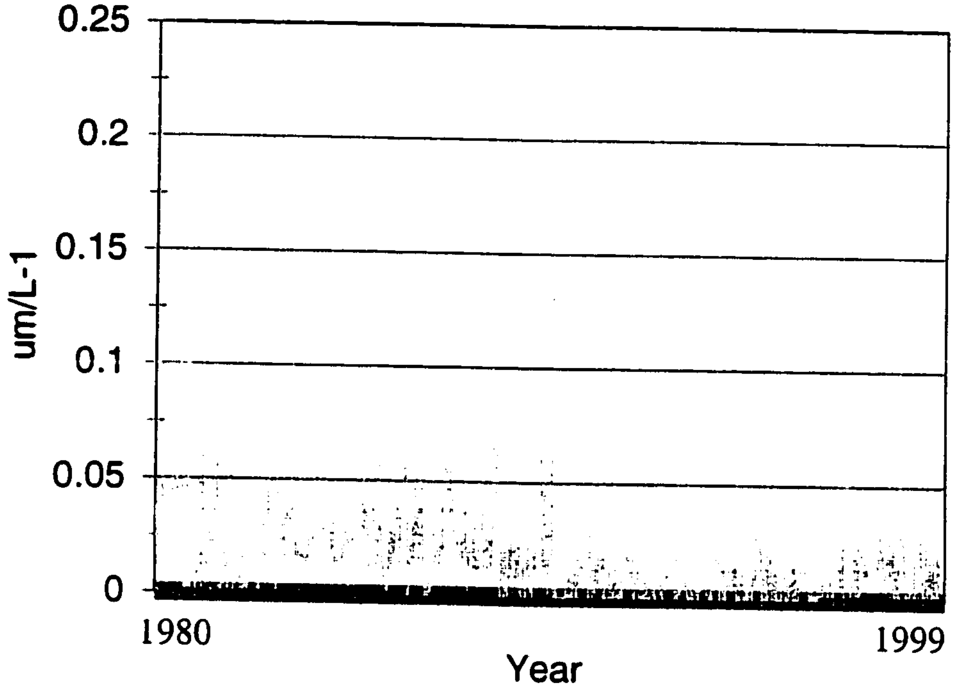


Figure 2.12.
Nitrate levels of water collected weekly at the Cobourg water treatment plant intake from January 1980 to October 1999 (MoEE, 1999).

2.6 Zebra Mussels in Lake Ontario

Two species of *Dressenidae* mussel have invaded the Great Lakes over the past two decades. The zebra mussel (*Dreissena polymorpha*) is believed to have arrived in the lower Great Lakes in 1985 or 1986 (Hebert et al., 1989). It is originally from western Russia and started spreading with the invention of steamships (Fenske, 1999). The quagga mussel (*D. bugensis*) arrived in 1991, being transported in the ballast tanks of ships (May and Marsden, 1992).

Dressenidae mussels are bivalve filter feeders that can filter a size range of particles from 0.36 μm to 40 μm (MacIssac, 1996; Roditi et al., 1996). The mussels filter phytoplankton, algae and suspended sediments as feed (Ma, 1996; Ma et al., 1999).

Individual mussels can filter up to 100 mL per hour (Kryger and Riisgard, 1988). In the lower Great Lakes, zebra mussel life span is up to 4 years while zebra mussels found in Russia live up to nine years (Chase and Bailey, 1999; Mackie et al., 1989).

Dressenidae mussels are believed to have had a significant impact on the Lake Ontario ecosystem and have become a major component of benthic communities (Dahl et al., 1995; Millard et al., 1996). The number of native bivalve species has not changed since the introduction of *Dressenidae* mussels in Lake Ontario, but populations have significantly declined (Stewart and Haynes, 1999). The non-native mussels are now a major food source for waterfowl, fish, crayfish and parasites (Fenske, 1999).

On a lake-wide scale, these mussels do not appear to be able to alter water transparency (Bailey et al., 1999). However, in shallower depths (1-15m), the mussels can considerably reduce suspended material (Bailey et al., 1999), improving water clarity and resulting in higher bottom temperatures and increased primary production, especially by aggressive and fast growing species such as algae (Mazumder, 1990; Nicholls and Hopkins, 1993).

According to Tyerman (1999), Dressenidae mussels were first observed at Presqu'ile Provincial Park in 1993. The mussels now cover the limestone shelves offshore of the park and swimmers must wear footwear to prevent being cut by them. In the fall and winter, the Park's shoreline is covered with a layer of mussels 15 cm deep and 1.5 m wide. The shells are ground up and washed away in the spring and early summer. The importance of *Dressenidae* mussels and their relationship with *Cladophora* will be discussed in detail in Chapter 5.

2.7 Aquatic invertebrate communities in the nearshore zone

Many aquatic invertebrates, including members of the Chironomidae, Oligochaeta, Gastropoda and Nematoda families inhabit the nearshore zone (Chilton et al., 1986). The nearshore zone is described as an area that extends lakeward from the shoreline to just beyond where the waves break (Komar, 1998). It is also referred to as the littoral zone, which is described as the area between land and lake where waves can move sediments (Summerfield, 1994).

Aquatic invertebrates inhabit the nearshore zone because of the presence of macrophytes such as *Cladophora,* which provide suitable habitat. Some invertebrates, such as the midge species *Psectrocladius limbatellus* graze on *Cladophora* (Chilton et al., 1986). Other invertebrates feed on the epiphytes that become trapped in *Cladophora's* filamentous branches (Rosen et al., 1981). A study by Pomeroy (1999) indicated that the *Cladophora* deposited on the beaches at Presqu'ile is the home to members of the invertebrate families summarized in Table 2.1. The invertebrates are a vital part of the Presqu'ile ecosystem and are preyed upon by 21 species of migrating shorebirds, diving ducks such as Oldsquaw and fish such as rock bass and crayfish (Ehrlich et al., 1988; Pomeroy, 1999).

Table 2.1.
Invertebrate families, their population and percentage of the total population found inhabiting *Cladophora* deposited on the beaches at Presqu'ile (Pomeroy, 1999).

Family	Number	% of total population
Chironomid	1360	94.4
Gammarus	41	2.8
Chaoborids	14	1.0
Prosobranchs	7	0.004
Molannideans	6	0.004
Cerotopogonids	5	0.003
Mermithids	4	0.003
Chryomellids	1	< 0.001
Hirudineans	1	< 0.001
Lamellibranchs	1	< 0.001

2.8 The Study Area

Presqu'ile Provincial Park is located on the northern shore of Lake Ontario, five kilometres south of the town of Brighton (Fig. 2.13). The Park's beaches are of significant economic value, generating approximately $300,000 in day use revenue annually (Mates, 1999). Less revenue is generated when large quantities of *Cladophora* are deposited along the shoreline and the area is not pleasant for swimming.

2.8.1 Site Description

Presqu'ile became designated as a Provincial Park in 1956 and currently averages 250,000 visitors per year (Mates, 1999). Approximately half of all visitors use the beach and it is an important staging area for migrating shorebirds such as Spotted Sandpipers, Sanderlings, Dunlin and Whimbrel in the spring and fall. This site was chosen because of the large accumulations of algae that are annually deposited on the recreational beach and a knowledge of the local area.

Presqu'ile is a tombolo that grows approximately two metres each year as sand is deposited in Popham Bay (Law, 1989). Popham Bay and the beach are the sediment sink for the Presqu'ile-Wellington littoral drift cell. The Presqu'ile-Wellington cell is contained by East Point (east of Toronto) in the west and Popham Bay and the Presqu'ile peninsula in the east. The drift direction in this cell is predominantly from west to east (Martini and Kwong, 1985).

Littoral cells are defined as zones of restricted long-shore sand transport (Peterson et al., 1991) and as semi-contained entities where one can better develop a budget (Komar, 1998). This zone is highly productive and important to the energy budget in lakes (Harrison and Hildrew, 1998). Although sediments are the predominant material studied in littoral cells, other materials such as macrophytes are transported and deposited. Presqu'ile's beach catches large quantities of algae and macrophytes, primarily *Cladophora* but also including *Potamagetin* and *Chara* that grow along the north shore of Lake Ontario (pers. obs). The result is a fouled beach that is unpleasant for recreational use.

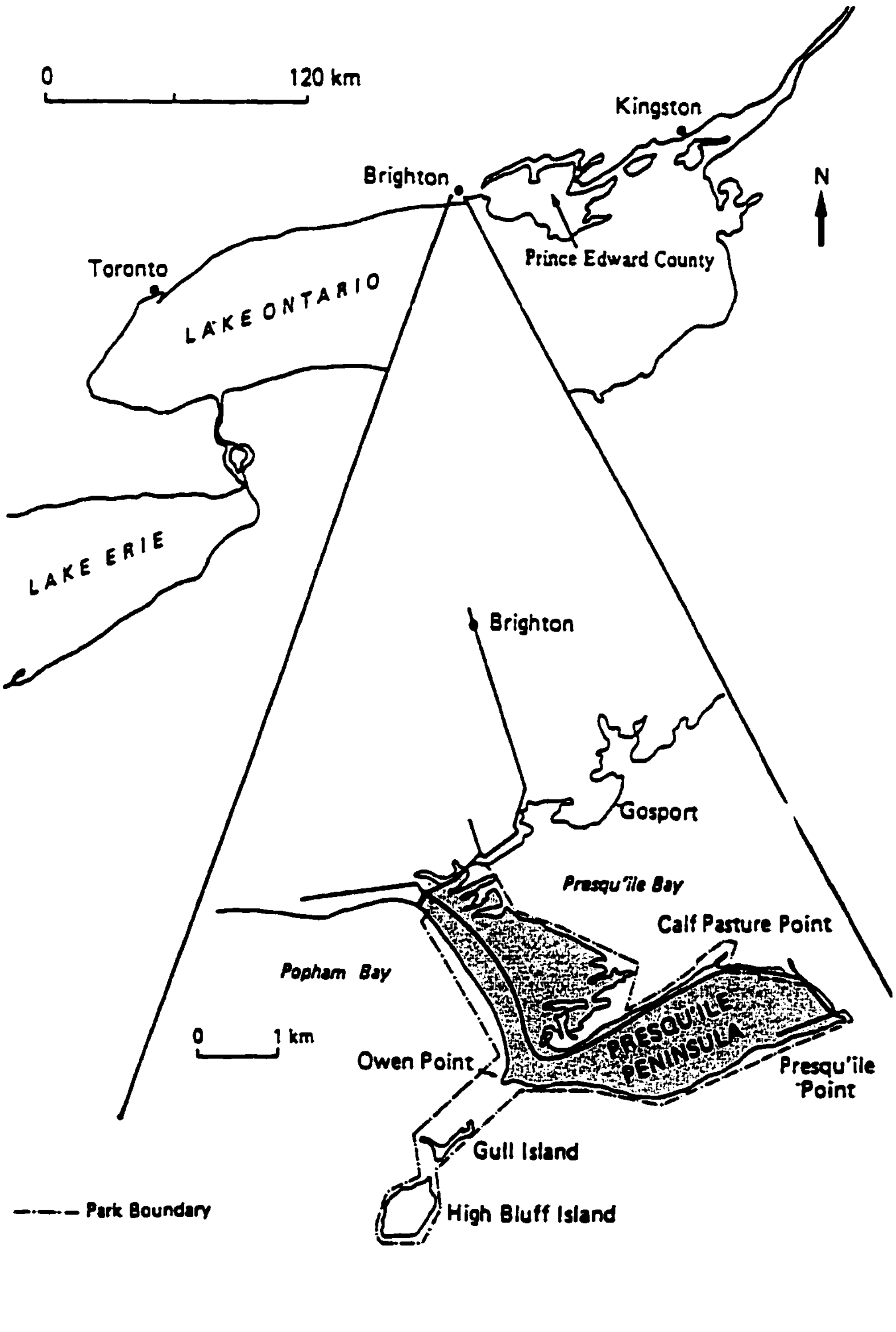


Figure 2.13.
The Location of Presqu'ile Provincial Park (Law, 1989).

2.8.2 History of *Cladophora* at Presqu'ile Park

According to park residents, large quantities of "heavy green moss algae" have been deposited on the beaches at Presqu'ile since the 1930s (Beach, 1999). In the 1940s, Beach (1999) described having to "wade forever to get through the stuff" on the recreational beaches and being unable to use the beaches from mid-July until mid-August. By 1950 there was a noticeable increase in algae growth in Presqu'ile Bay and the problem is believed to have peaked in the 1960s and 1970s, when algae began to be deposited at the boat launch at Calf Pasture Point (Fig. 2.13). In 1975, the Park purchased an algae collector to help maintain the beaches for recreational use (Shear and Konasewich, 1975). The collector was ineffective and its use was discontinued after 1976 (Brown, 1999). The present cost of algae clean-up from the beaches at Presqu'ile accounts for almost 10% of the annual budget of the park (Haagsma, 1999). Presqu'ile Park's budget for algae clean-up between 1975 and 1999 appears to have increased by $4,900 (Table 2).

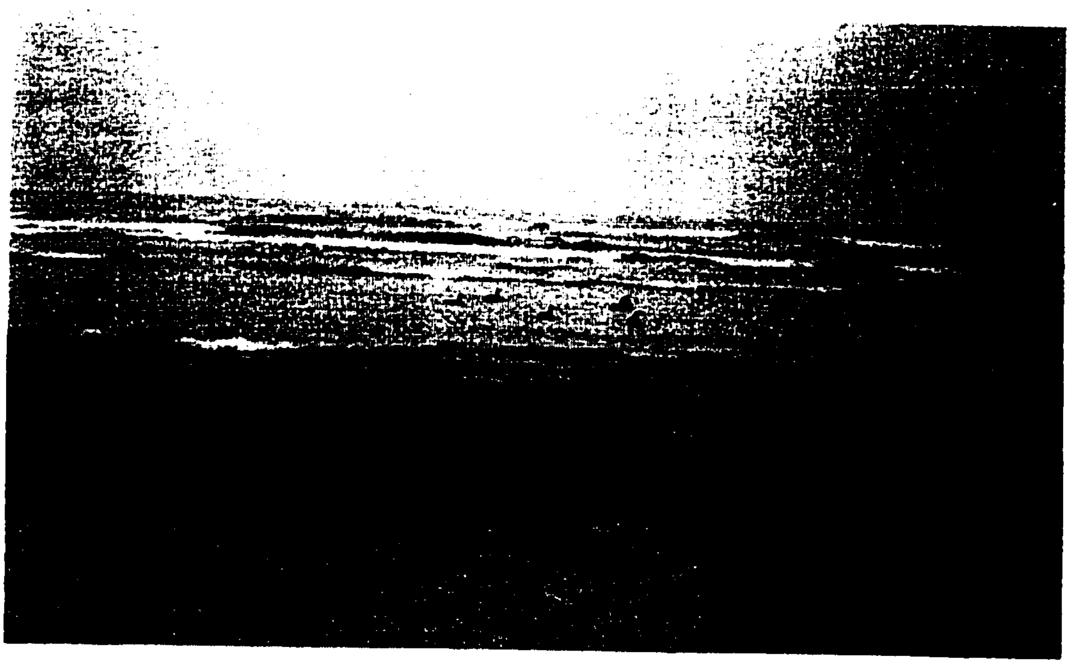
Table 2.
Algae cleanup cost at Presqu'ile in 1975 and 1999 (Shear and Konasewich, 1975:143; Haagsma, 1999).

Costs	1975	1999
Labour	$5,400	$7,200
Equipment	$9,000	$12,100
Total	$14,400	$19,300

When inflation is factored into the costs, algae clean-up expenses have actually declined by $28,020 in 1999 dollars from 1976 to 1999 (Bank of Canada, 2000). This indicates either that the government wasted money cleaning the beach in the 1970s or there was significantly more algae.

Currently, algae clean-up efforts focus on the north end of the beach and less of the beach is cleaned than in the past because of increasing quantities of algae. According to Painter and Kamaitis (1987), from 1972 to 1983 *Cladophora* growth was measured at Presqu'ile and decreased by 70%. Since the early 1990s, Tyerman (1999) believes *Cladophora* growth has increased and large quantities of algae are currently being deposited on the beach (Fig.2.14 a,b).

a)



b)

Figure 2.14.
a) *Cladophora* deposited on Beach 1 (Fall 1997).
b) *Cladophora* deposited on Beach 4 (Fall 1997).

2.8.3 The Suitability of Presqu'ile for *Cladophora* Growth

The nearshore area around Presqu'ile Provincial Park provides ideal habitat for *Cladophora* growth. The park is surrounded by the bedrock and glacial tills required for *Cladophora* growth and over-wintering (Fig. 2.4).

Phosphorus levels have been monitored by Ontario Parks and by Maricic (1998) in Popham Bay (Fig. 2.13) and are well below the minimum level of 0.03 mg/L that is required according to Shear and Konasewich (1975) for significant *Cladophora* growth (Fig. 2.15).

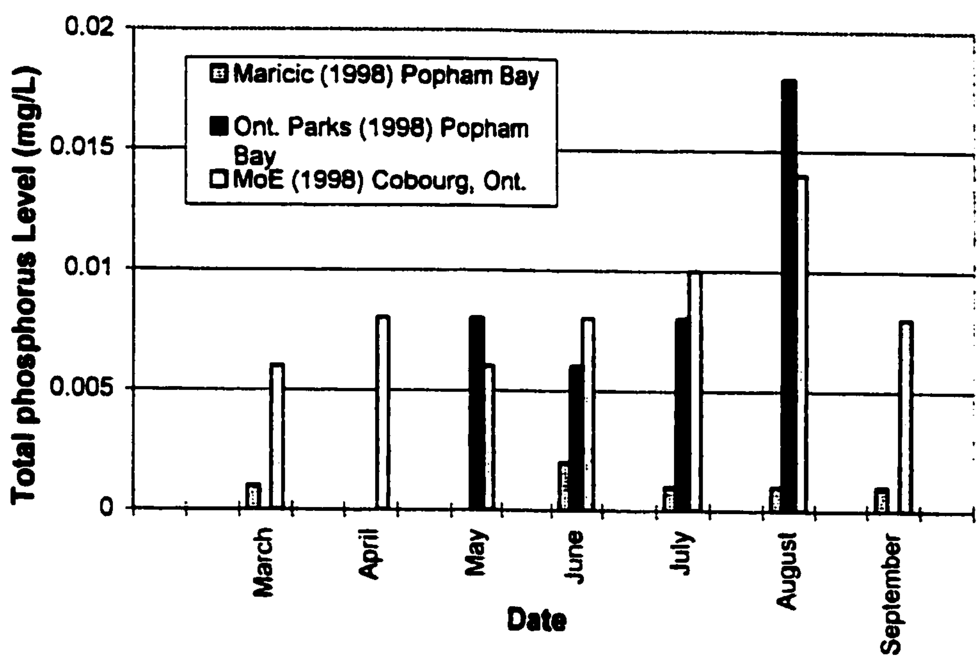


Figure 2.15.
Total Phosphorus (TP) in the water measured by Maricic (1998) and Ontario Parks (1998) at Presqu'ile in Popham Bay and TP data from Cobourg, Ontario collected by the Ministry of Environment and Energy for comparison. *Cladophora* requires a minimum of 0.03 mg/L total phosphorus for excessive growth (MoEE, 1999).

The variability in the results is partially due to the highly variable nature of TP levels, but also due to different sampling days and different lab techniques used. The low TP levels found in Popham Bay are unlikely to represent the nutrient availability for *Cladophora* growth on the limestone shelves around Presqu'ile Park. Point source nutrient experiments by Neil and Jackson (1982) have shown that small quantities (0.35 kg/day) of additional phosphorus can result in an increase of up to 90% in algae cover.

A source of nutrients for *Cladophora* growth at Presqu'ile is the colonial waterbird colony. Hoyer and Canfield (1994) found a positive correlation (r^2=0.61) between bird numbers and algae biomass, and the trophic status of the lake. Bird excrement from colonies such as Gull and High Bluff Islands have been found to provide nutrients for *Cladophora* growth (Goulden et al., 1970). The colonial waterbird colony located on Gull and High Bluff Islands is the home to over 200,000 birds (Fig. 2.16).

Figure 2.16.
The Bird colony at Gull Island, Presqu'ile Provincial Park.

The wind and waves at Presqu'ile fuel littoral cell circulation, which provides the water movement required by *Cladophora* for optimal growth (Whitton, 1970). Increased rates of flow allow *Cladophora* to make "more efficient use of nutrients" and it is "most prolific" where currents keep nutrient levels high, providing source waters are enriched (Casey et al., 1973; Whitton, 1970).The relationship between the speed and direction of currents and winds is the most apparent in the top 10 metres of the epilimnion, where *Cladophora* growth occurs (Fig. 2.17). Much of the success of *Cladophora* as a species can also be attributed to its life cycle. By over-wintering as an akinete attached to the substrate, Cladophora can essentially function as a perennial (Rosemarin, 1985).

2.9 Summary

Cladophora growth is influenced by many factors, including nutrients, water clarity and water temperature. Presqu'ile provides ideal conditions for *Cladophora* growth. The Park is surrounded by limestone and water movement caused by wave action ensures nutrients for growth. Various techniques were used to determine *Cladophora* growth and deposition and the methods used to obtain the data will be examined in the following chapter.

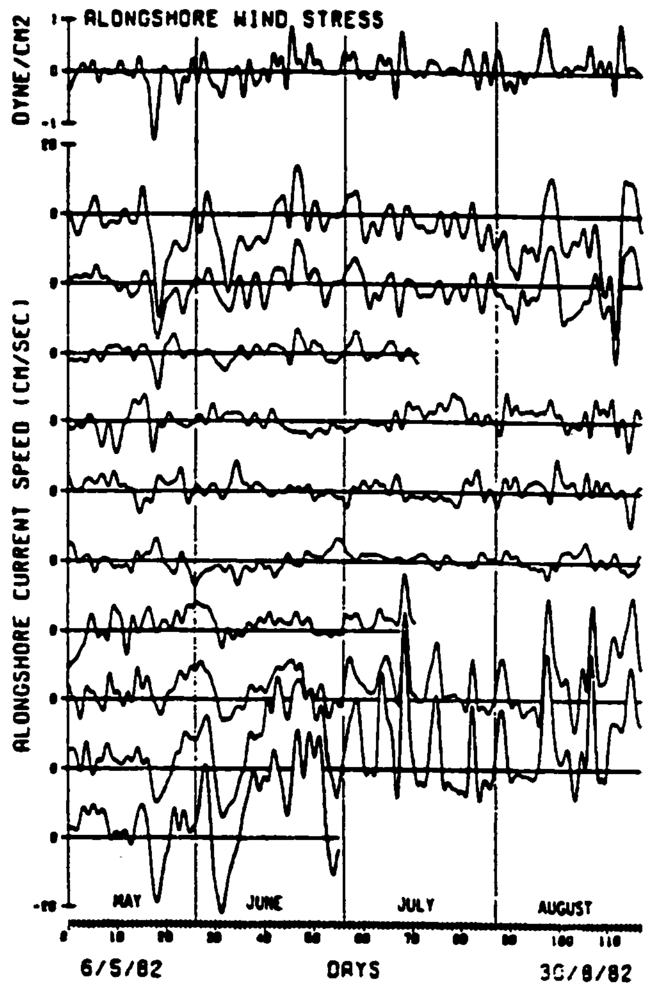


Figure 2.17.
The relationship between wind and current velocity in the epilimnion. For each of the 10 sites, current speed is in intervals of 20 cm/sec parallel to the shoreline. (Simons and Schertzer, 1989).

Chapter 3

Methodology

3.1 Introduction

The field and laboratory methods used in this study are outlined in the following sections. Not included is a description of the challenges researchers face when working underwater. They are accurately described by Littler and Littler (1973:200), who stated that "Studying subtidal algae with SCUBA is analogous to studying chaparral in a heavy rain, with 200 mph winds that change direction every several seconds, by crawling around in a raincoat, observing through a stovepipe, and breathing through a hose." Despite the challenges, accurate measurements were collected.

3.2 Field Methods

The field study took place between June 6 and September 19, 1999 at Presqu'ile Provincial Park (PQP). The dates of sampling are presented in Chapter 4. Sampling began once proper SCUBA certification and equipment were obtained and a suitable site analysis was completed to select research sites. Ideally, samples would have been collected every two weeks, particularly when maximum growth occurs in July (Duthie and Jones, 1990;Westlake,1969). However, because of mechanical problems with the boat, field assistant availability and weather, only monthly sampling at each site was possible.

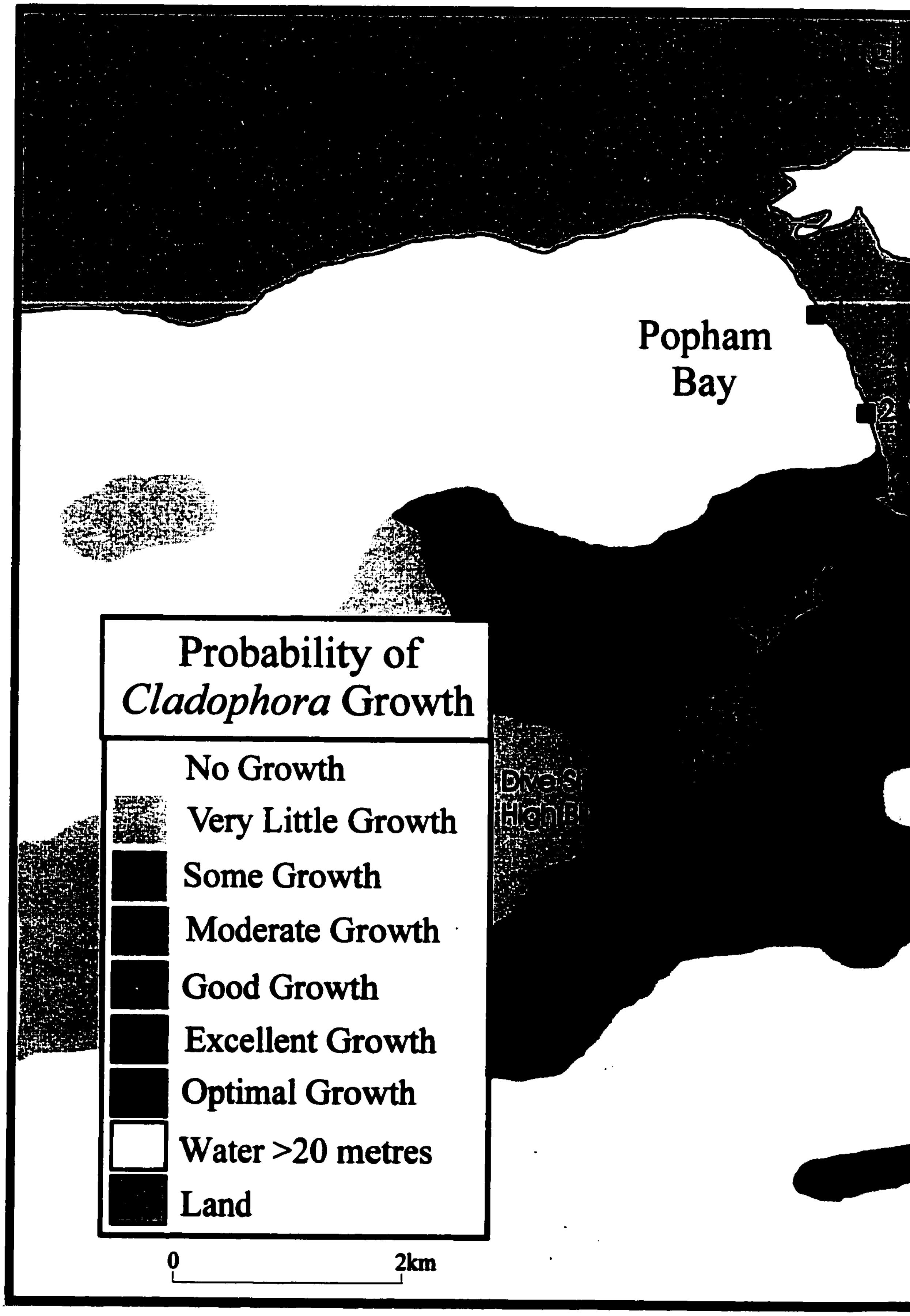
3.2.1 Site Selection

Sample site locations for algae collection were selected based on a suitable site analysis of the area. The suitable site analysis was done in Arcview by assigning values to lake depth and substrate type and multiplying the two. The two variables were multiplied rather than added to ensure that no site was selected that did not fulfil one of the growth requirements for *Cladophora* because sand was present or water depth was over 20 metres.

The resulting product ranked potential growth on a scale of 0 to 12, with no growth occurring at 0 and optimal growth conditions found at 12 (Figure 3.1). Values were assigned to lake depths based on their suitability for *Cladophora* growth. Shallow areas were given larger values than deeper areas based on Whitton (1970), who stated that better light availability will result in increased *Cladophora* growth (Table 3.1).

Table 3.1.
The assigned numerical value of different depths based on suitability for *Cladophora* growth. Higher values are indicative of a higher probability of *Cladophora* growth.

Depth	Value
0-2 metres	4
2-5 metres	3
5-10 metres	2
10-20 metres	1



Popham Bay
Probability of *Cladophora* Growth
No Growth
Very Little Growth
Some Growth
Moderate Growth
Good Growth
Excellent Growth
Optimal Growth
Water >20 metres
Land
0
2km

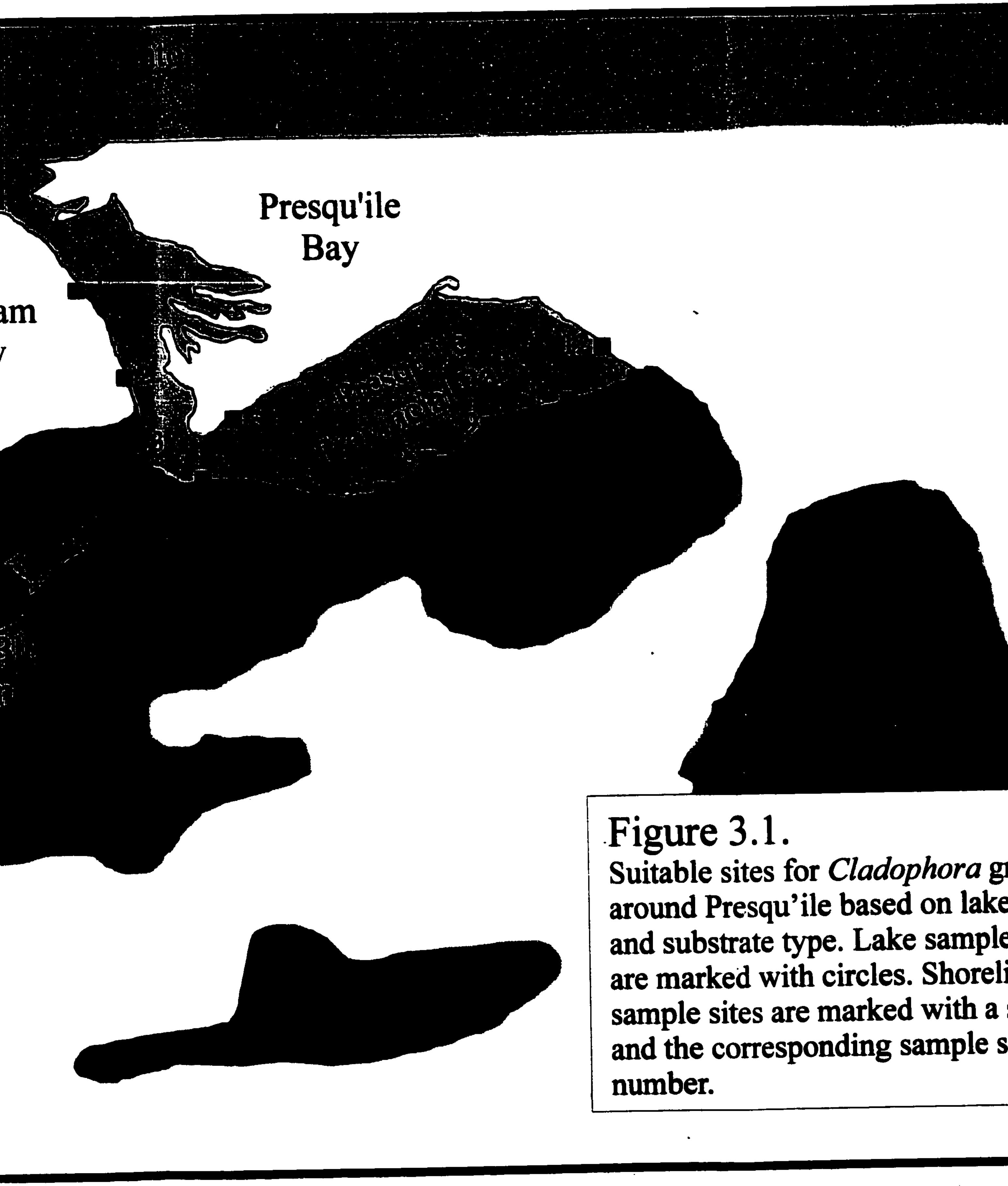


Figure 3.1.
Suitable sites for *Cladophora* gr
around Presqu'ile based on lake
and substrate type. Lake sample
are marked with circles. Shoreli
sample sites are marked with a
and the corresponding sample s
number.

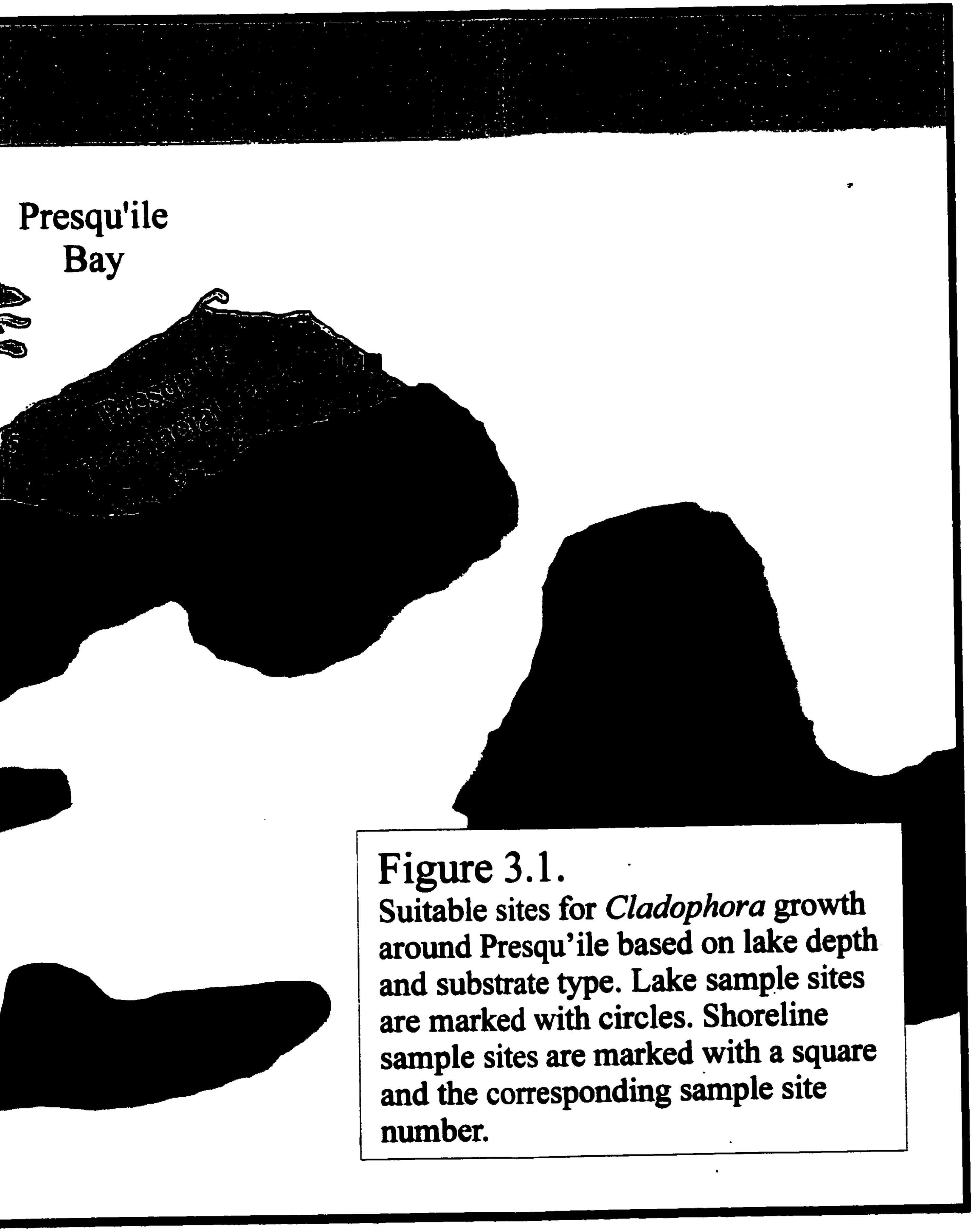


Figure 3.1.
Suitable sites for *Cladophora* growth around Presqu'ile based on lake depth and substrate type. Lake sample sites are marked with circles. Shoreline sample sites are marked with a square and the corresponding sample site number.

Values were also assigned to the Lake Ontario substrates in the Presqu'ile area. Bedrock was given the highest value since it is the most suitable habitat for *Cladophora* growth and there is the highest probability of finding growth there (Thurman and Kuehne, 1952). Sand was given a value of 0 since there is zero probability that *Cladophora* growth will be found there. Sand does not support any *Cladophora* growth because of its dynamic nature (Thurman and Kuehne, 1952). A complete list of substrate values can be found in Table 3.2.

Table 3.2.
The assigned numerical values of the different substrates. Higher values are indicative of a higher probability of *Cladophora* growth.

Substrate	Value
Bedrock	3
Glacial Sediments	2
Sand and Boulders	1
Sand	0

Two factor that were not included in the suitable site analysis were wind and wave action. They were omitted because, although they result in increased sloughing, they do not result in *Cladophora* growth being stopped unless they are accompanied with large quantities of moving sediment (Auer et al., 1982a; Whitton, 1970).

3.2.2 Boat Sampling

A 14 foot (4.5 metre) aluminum boat with a 25-horsepower outboard motor was used to reach the sample sites. Algae samples were collected from depths of 9.1, 4.6 and 1.5 metres at two sites for the duration of the study period.

The depth from the water surface to the bottom was measured by lowering a marked rope with a weight attached into the water once the boat was anchored. At each depth, the collector would enter the water with SCUBA equipment and collect the algae growing on the bottom from four quadrats. The quadrats were selected by randomly dropping a 25-cm by 25-cm wire square from 1.5 metres above the bottom (Millner et al., 1982). All organic matter, including algae, zebra mussels and macrophytes were removed from the bottom and placed in fabric sample bags. The samples were brought to the surface and transferred to plastic Ziplock™ bags.

Sample location was measured with a Garmin 12 GPS unit and a compass and recorded to ensure accurate mapping. Current speed was measured with a marsh McBurny current meter placed 0.5 meters from the bottom of the lake to determine the amount of water movement at different depths. Wind direction was measured using the dive flag affixed to the back of the boat.

Water samples were taken at the surface and bottom at sample sites in 250-mL bottles in order to do nutrient analysis. Water temperature was measured from the sample bottles with an electronic thermometer immediately after they were collected to determine if there was a gradient between the surface and the bottom. Secchi depth was measured using a 20-cm black and white Secchi dish to determine water clarity and light penetration, factors critical to *Cladophora* growth (Wetzel and Likens, 1991).

3.2.3 Shoreline Sampling

Twelve sites around Presqu'ile were selected to be harvested weekly to monitor *Cladophora* growth and deposition on the shoreline (Fig 3.1). Locations were marked with a Garmin 12 GPS and sampled from July 15 to September 19, 1999. Samples were collected from each location by placing a 25-cm by 25-cm quadrat in the water 0.5 metres from the shoreline. All organic matter, including live and dead algae, zebra mussels and macrophytes were then removed from the bottom and placed into Ziplock™ bags. Observations were made on whether the algae was growing in-situ or were deposited by wave action.

3.2.4 Beach Sampling

In order to have an aesthetically pleasing swimming beach, algae was collected from the shoreline between beach 1 and beach 3 by park maintenance crews with a tractor and loaded into a 3-ton (6750-kg) dump truck. The algae was transported and dumped at beach 3. The number of full truck loads of algae collected daily was recorded on standardized forms which were collected weekly. On August 30, 1999, a 25-litre sample of material from the "algae dump" located on beach 3 was collected to be analyzed to determine the quantity of organic material in the samples.

3.2.5 Sample Storage Methods

Algae samples were collected and placed in Ziplock™ freezer bags. Water samples were collected in 250-mL sample bottles. All samples were frozen within three hours of being collected. Samples were stored in a chest freezer for the duration of the study period. Samples being transported from Presqu'ile to Waterloo for analysis were placed in coolers packed with ice cubes.

3.3 Laboratory Methods

Algae was analyzed at Wilfrid Laurier University and the University of Waterloo in Waterloo, Ontario between October 1999 and February 2000. Water samples were analyzed by the Ontario Ministry of the Environment and Energy, Etobicoke laboratory.

3.3.1 Algae samples

Algae samples collected with SCUBA and from the 12 sites around Presqu'ile Provincial Park were analyzed using the same methods. Samples were thawed in a water bath and the *Cladophora*, Zebra Mussels, invertebrates and other macrophytes were separated by hand (Chilton et al., 1986). Samples were then baked in a drying oven at 105°C for a minimum of 24 hours (USEPA, 1973). The dried samples were then re-sorted by hand and divided into five groups: *Cladophora*, zebra mussels, midge larvae, Caddisfly larvae and other vegetation. Once separated, the *Cladophora* was weighed with an electronic balance and recorded in order to calculate the g/m^2 dry weight.

Samples of the dried *Cladophora* were used to determine organic content and tissue Phosphorus (Millner et al., 1982). To determine organic content, loss on ignition (LOI) method was used. The dry *Cladophora* was placed in a crucible, weighed, heated in a high-temperature oven at 550°C for 1 hour and then weighed again (Dean, 1974).

Tissue phosphorus of the *Cladophora* samples was determined by digesting the samples and using a mass spectrometer. A full description of the tissue phosphorous method used can be found in Carnes and Millner, 1980.

Algae collected from the algae pile was placed in an oven at 105°C for 24 hours. *Cladophora* were then baked for 1 hour at 550°C in ceramic crucibles to determine the organic content of the sample collected.

3.3.2 Water samples

Water samples were analyzed for total phosphorus (TP), phosphate (PO_4P), total Kjeldahl nitrogen (TKN), nitrate (NO_3), nitrite (NO_2), ammonia and ammonium (NH_4), silicon (Si) and carbon (C) by the Ontario Ministry of the Environment and Energy, Etobicoke laboratory. Conductivity and pH were measured electronically at Wilfrid Laurier University after water samples were thawed in a water bath.

3.3.3 Zebra mussels

Zebra mussels were separated from the algae samples by hand, and baked in a drying oven at 105°C for a minimum of 24 hours. The samples were then weighed with an electronic balance in order to calculate the g/m² dry weight (USEPA, 1973).

3.3.4 Aquatic Invertebrates

Invertebrates were removed by hand from the sample before and after being baked in a drying oven at 105°C for a minimum of 24 hours (Chilton et al., 1986). The presence of members of the Mermithidae family was recorded before baking since their soft bodies are destroyed in the oven. After baking, invertebrates were divided into two basic groups based on their form. All tube-carrying invertebrates were classified as caddisflies and all others were classified as scuds (freshwater shrimp).

3.4 Statistics

Linear regression tests were done on some of the water chemistry and algae data with SPSS for Windows release 6.0 (Student Version). Linear regression was chosen to investigate if this study found similar relationships between *Cladophora* and its environment as other studies. The results must be approached with caution since the sample size was small. Because of the difficulty in collecting high numbers of *Cladophora* samples, linear regression statistics are seldom used (Milner et al, 1982; Neil and Jackson, 1982).

3.5 Summary

Because of the challenges of the sampling environment and the resulting small number of samples, it is critical that there is a standard for how the samples are collected, stored and transported. This study followed proven methods described by Littler and Littler (1973) and Millner at al (1982). Laboratory work was conducted by trained Ontario Ministry of the Environment staff to ensure accurate results.

Chapter 4

Results

4.1 Introduction

This chapter will present the results of this study. Discussion of the results will take place in Chapter 5.

4.2 Physical characteristics of the study site

Lake Ontario conditions at the study sites were monitored whenever samples were collected. Secchi depth was measured at the deepest sites and light is not considered to be a limiting factor to *Cladophora* growth in the area since Secchi disk transparency generally exceeds the depth of the sample site (Millner et al, 1982). Temperature was measured at the surface and at the bottom at many sites while pH and conductivity were derived from surface water samples at the deepest sites (Table 4.1). The temperatures recorded are all within the range observed by Dobson (1984) over the duration of the study period.

From July to the end of the study period, water temperature at the surface and at the bottom was within 2.5°C of the optimal temperature for *Cladophora* growth. Water temperature reached its highest level, 22.5°C, on July 22. The timing of the maximum temperature corresponds with the timing of maximum *Cladophora* biomass and sloughing which will be discussed in the following sections.

At the beginning of the study season the lake was thermally stratified in the nearshore zone. This stratification had virtually disappeared by July 13, when the top and bottom water temperatures were the same. Water temperature at the surface and at the bottom was within 1.5°C for the remainder of the study.

The pH measured at 10 sites was between 7.24 and 8.88 with a mean of 8.208. This is below the Lake Ontario ranges presented by Dobson (1984) that are between 8.3 and 8.58. However this is influenced by the fact that the Presqu'ile samples were measured at 18 °C while the Dobson (1984) samples were tested at 25 °C.

Current speed and wind direction were measured but did not receive significant consideration in this study for several reasons. The results were biased by the fact sampling only occurred on days with minimal wind and waves, not typical Lake Ontario conditions. Also, samples were only collected for the first two months of the study, not the entire study period. The general trend was that maximum current velocity was associated with westerly winds. This is expected since it relates to the longest fetch period.

Analysis was done on bottom water samples for ammonia and ammonium, nitrate and nitrite, total phosphorus and total Kjeldahl nitrogen for both diving sites. Table 4.2 presents a complete list of water chemistry data for Site 1. Ammonia and ammonium levels should observed with caution since they cannot be accurately measured in a pH under 9.

Table 4.1.
Physical characteristics of Lake Ontario at the study sites throughout the study period.

Date	Location	Depth (metres)	Temp. (Top) (Celsius)	Temp. (Bot) (Celsius)	Secchi (metres)	pH	Cond.
04\06\99	site 1	9.1	11.6	7.9			
11\06\99	site1	9.1	15.4		9.1	8.88	0.2
11\06\99	site1	4.6	16.7				
16\06\99	site2	9.1	16.3	11.6	9.1	7.84	0.213
16\06\99	site2	4.6	15.4				
16\06\99	site2	1.5	17				
16\06\99	site1A	1.5					
13\07\99	site1	7.6	18.5	18.5	7.6	7.43	0.828
13\07\99	site1	4.6		18.7			
13\07\99	site1	1.5		19.4			
16\07\99	site1A	4.6	20.4	19.1	4.6	8.8	0.206
16\07\99	site1A	1.5	21.2				
22\07\99	site2	9.1	22.6	21.8		8.77	0.272
22\07\99	site2	4.6	22.5	22.3			
22\07\99	site2	1.5	22.5		1.5		
28\07\99	site1	9.1	18.8				
28\07\99	site1 - verif	9.1	18.4			7.24	0.185
28\07\99	site1	4.6	18.9	17.1			
28\07\99	site1	1.5	18.9	18.5	1.5		
23\08\99	site 1	9.1	21	20	9.1		
23\08\99	site 1	4.6	21.2	20.8	4.6	8.4	0.214
23\08\99	site 1	1.5	20.8	21			
23\08\99	site 2	9.1	21.2	20.8	9.1	7.67	0.215
23\08\99	site 2	4.6	21.3	21.2			
23\08\99	site 2	1.5	21.4	21.6			
18\09\99	site 2	9.1	18.2	18.1	9.1	8.3	0.164
18\09\99	site 2	4.6	18.1				
18\09\99	site 1	9.1	18.4	18.1	9.1	8.75	0.255
18\09\99	site 1	4.6	18.3				

Table 4.2.
Water Chemistry at Site 1.

Date	Ammonia & ammonium (mg/l)	Nitrate and Nitrite (mg/l)	Total Phosphorus (mg/l)	Total Kjeldahl Nitrogen (mg/l)
June 11	0.006	0.327	0.004	0.2
July 13	0.008	0.279	0.004	0.22
July 28	0.036	0.345	0.006	0.24
August 23	0.016	0.068	0.01	0.24
September 18	0.012	0.205	0.004	0.2
Average	0.016	0.245	0.006	0.22

General trends observed at Site 1 were:

- ammonia and ammonium levels peaked in late July and then declined.
- highly variable nitrate and nitrite levels were recorded with a minimum of 0.068 mg/L in August.
- low total phosphorus levels peaked August 23.
- total Kjeldahl nitrogen was stable throughout the study period

Table 4.3 presents a complete list of water chemistry data for Site 2.

Table 4.3.
Water Chemistry at Site 2.

Date	Ammonia & ammonium (mg/l)	Nitrate and Nitrite (mg/l)	Total Phosphorus (mg/l)	Total Kjeldahl Nitrogen (mg/l)
June 16	0.026	0.358	0.01	0.24
July 22	0.012	0.169	0.016	0.28
August 23	0.016	0.047	0.04	0.22
September 18	0.012	0.188	0.092	0.36
Average	0.017	0.191	0.0395	0.28

Water samples from Site 2 showed the following general trends:

- ammonia and ammonium levels peaked in June and then remained stable.
- nitrate and nitrite levels declined from June to a minimum of 0.047 mg/L in August.
- total phosphorus levels rose over the duration of the study.
- Total Kjeldahl nitrogen were stable from June to August then rose in September.

Study season averages for ammonia and ammonium, nitrate and nitrite and total Kjeldahl nitrogen recorded at Sites 1 and 2 were very similar. However, total phosphorus was over 7 times higher at Site 2 than at Site 1. This is related to the bird colony located near Site 2 and will be discussed in the following Chapter.

On September 18 water samples were collected at Sites 1 and 2 and three locations spaced evenly in between to see if a gradient existed between the Islands and the Densen cottage. The results indicate similar water chemistry in all the locations except at Site 2 (see Table 4.4).

Table 4.4.
Water Chemistry on September 18 at Site 1, Site 2 and three locations in between.

Location	Ammonia & ammonium (mg/l)	Nitrate and Nitrite (mg/l)	Total Phosphorus (mg/l)	Total Kjeldahl Nitrogen (mg/l)
Site 1	0.012	0.205	0.004	0.2
Chatterton Point	0.044	0.131	0.012	0.28
Lakeside Campground	0.016	0.179	0.004	0.2
Gull Island	0.016	0.183	0.004	0.2
Site 2	0.012	0.188	0.092	0.36

The Chatterton Point site had higher ammonia and ammonium levels and lower nitrate and nitrite levels than the other sites. This may be because of the limestone shelf and shallow water (>3m) in the sampling area.

4.3 *Cladophora* growth- Biomass and Tissue Phosphorus

Results of samples collected at depths of 1.5, 4.6 and 9.1 metres indicate that *Cladophora* growth peaked from the 13th to the 28th of July at Site 1 (Fig 4.1).

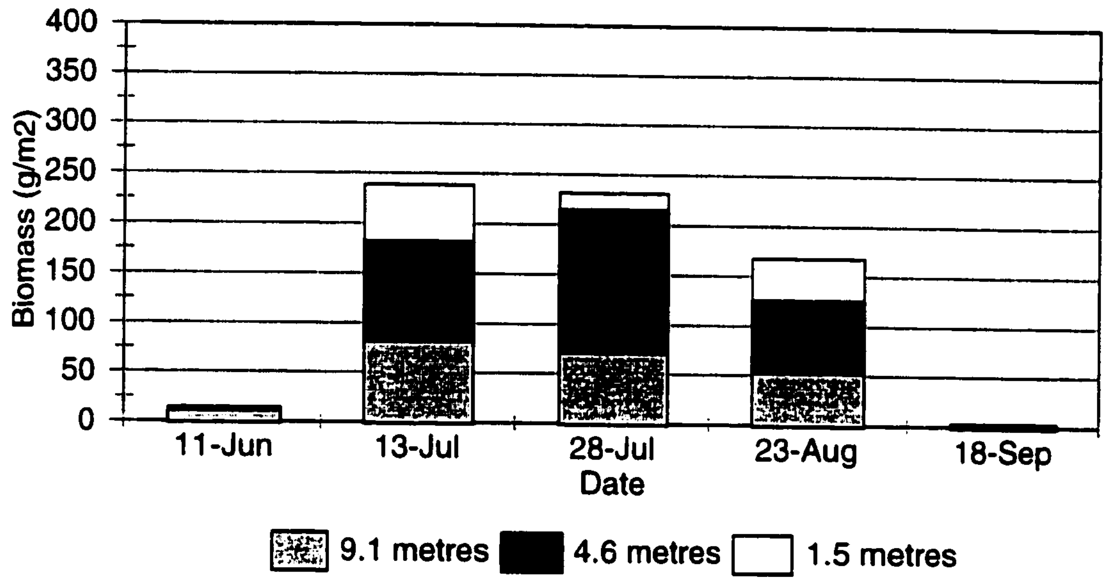


Figure 4.1.
Cladophora Biomass at site 1 on each of the sampling dates.

Maximum biomass measured was 238.24 g/m^2 on July 13, slightly more than the 231.6 g/m^2 measured on July 28. On both dates *Cladophora* growth occurring at a depth of 4.6 metres composed almost 50% of the total sample weight collected. Growth at 9.1 metres peaked at 83.88 g/m² on July 13 and declined to 72.48 g/m² on July 28 to 55.96 g/m² on August 23 and finally 2.68 g/m² on September 18.

Site 2 provided similar results with regard to the timing of maximum *Cladophora* growth. Peak biomass was measured on July 22 (Figure 4.2). Maximum biomass measured was 391.76 g/m² on July 22 at site 2, considerably more than the 238.24 g/m² measured at site 1 on July 13. The optimal depth for *Cladophora* growth at site 2 was 1.5 metres. The biomass at this depth constituted 62% of the total sample weight on July 22 and 84% of the total sample weight on August 23. Less *Cladophora* growth occurred at 9.1 metres at site 2 compared to site 1, but with the exception of the biomass collected at 1.5 metres on July 22, site 2 produced considerably less algae overall. Further research was required to determine if more *Cladophora* growth occurred at site 2 on July 22 or if maximum biomass occurred between the sampling dates at site 1 and was missed.

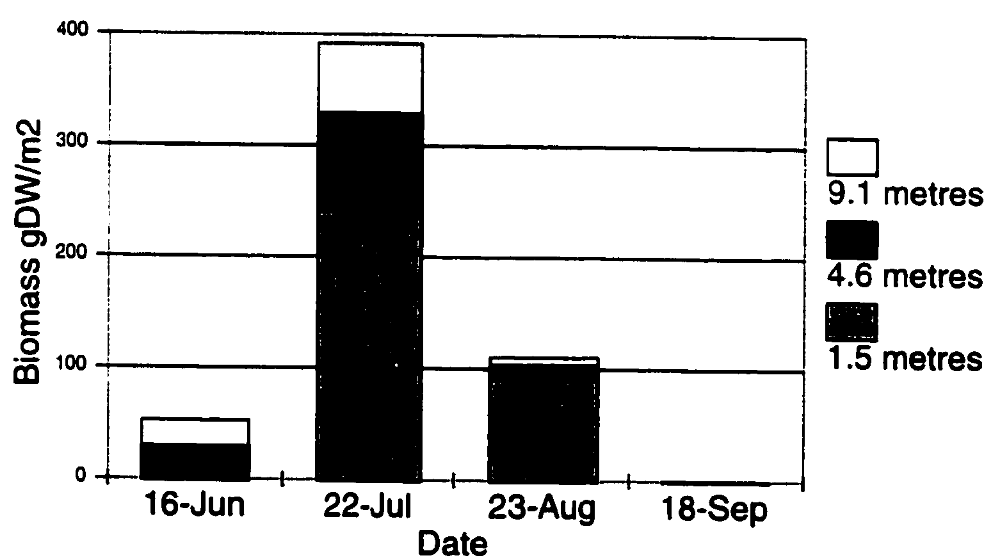


Figure 4.2.
Cladophora Biomass at site 2 on each of the sampling dates.

Cladophora was collected from site 1a on June 16 and July 16. Sampling after July 16 was stopped because of time limitations. The biomass collected at different depths is found in Table 4.5.

Table 4.5.
Cladophora Biomass at site 1a on June 16 and July 16.

Depth	June 16	July 16
1.5 metres	42.13	69.3
5 metres	NS	71.96
Total	42.13	141.26

NS- No Sample

More growth was recorded at site 1a than at sites 1 and 2 on June 16. This is likely related to the wave shadow created by Gull and High Bluff Islands, which shield site 1a from the dominant south-western winds and waves (Brebner and LeMéhauté, 1958). The higher biomass early in the season is also related to nutrient availability, which will be discussed later in this section. Total biomass collected at site 1a on July 16 was 141.26 g/m^2, comparable to the 154.36 g/m^2 measured at depths of 1.5 and 4.6 metres at site 1 three days earlier.

Tissue phosphorus analysis was done to determine if the *Cladophora* growing around Presqu'ile was phosphorus limited. When the results were plotted on the curve of tissue phosphorus and net specific growth rate proposed by Auer and Canale (1982b), it indicated that the *Cladophora* were most phosphorus limited from July 13 to the 28 (Fig 4.3). This period of limitation from July 13 to 28 was also the period of maximum

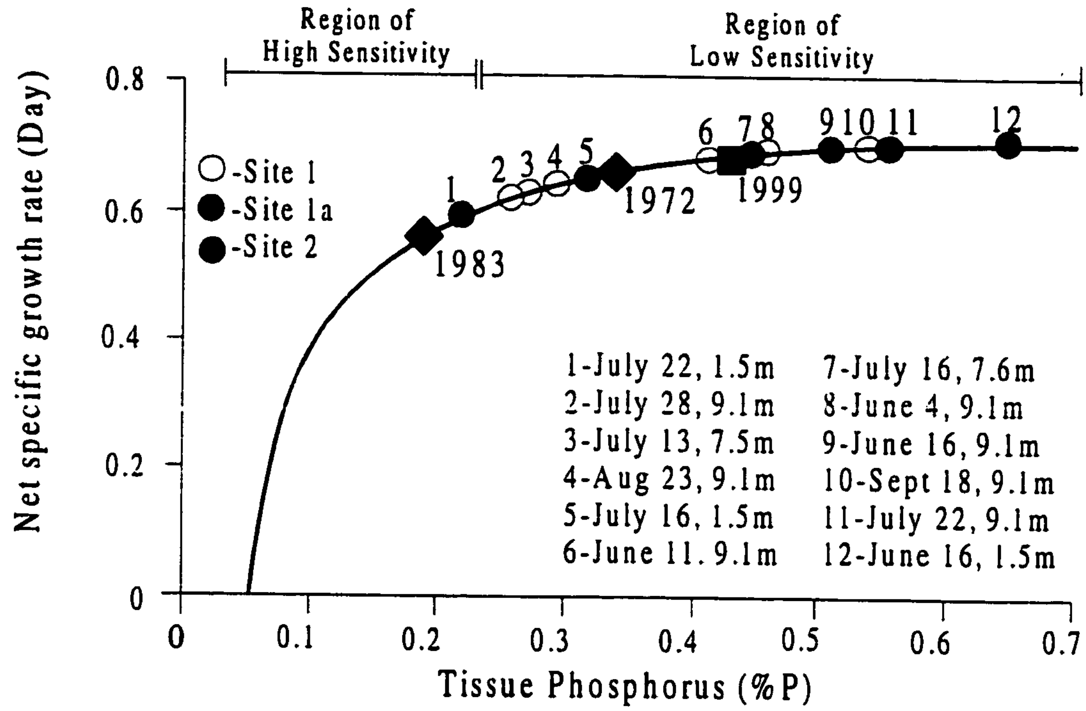


Figure 4.3.
The relationship between net specific growth rate and tissue phosphorus in *Cladophora* at Presqu'ile. The diamonds are the measurements recorded at Presqu'ile in 1972 and 1983 by Painter and Kamaitis (1988) and the square is the 1999 average.

biomass at all of the sites. Millner et al., (1982) also observed that the period of *Cladophora* detachment is associated with lower internal nutrient levels. The lowest tissue phosphorus level was 0.23% and it occurred at site 2 where the highest biomass was recorded, 243.12 g/m² at 1.5 metres on July 22. This sample is the only one which lies in the region of high sensitivity to changes in phosphorus as defined by Auer and Canale (1982b). The pattern of low tissue phosphorus and high biomass exists for samples 1 through 3 and 5 found on Fig. 4.3. The exception is sample 4, which was collected from site 1 on August 23 and may be contaminated because of the sand that was deposited on that site. Painter and Kamaitis (1987) did loss on ignition on all samples before testing for tissue phosphorus to determine an ash-free dry weight and eliminate differences in ash content in samples from different years and different depths, a method not used by this author which could have influenced tissue phosphorus results.

4.4 Shoreline and Beach Samples

The general pattern of growth at the 12 sites surrounding Presqu'ile was a peak in mid- to late July followed by sporadic growth for the remainder of the season (Fig. 4.4). These results are a combination of *Cladophora* growth at the sites and deposition. In many locations on July 13 and 23, *Cladophora* deposition in the nearshore area extended more than 1 metre from shore where sampling occurred so the sloughed algae was also included in the biomass results. When the total biomass collected at the different sites by date is grouped, it clearly shows periods of peak growth and deposition (see Fig. 4.5).

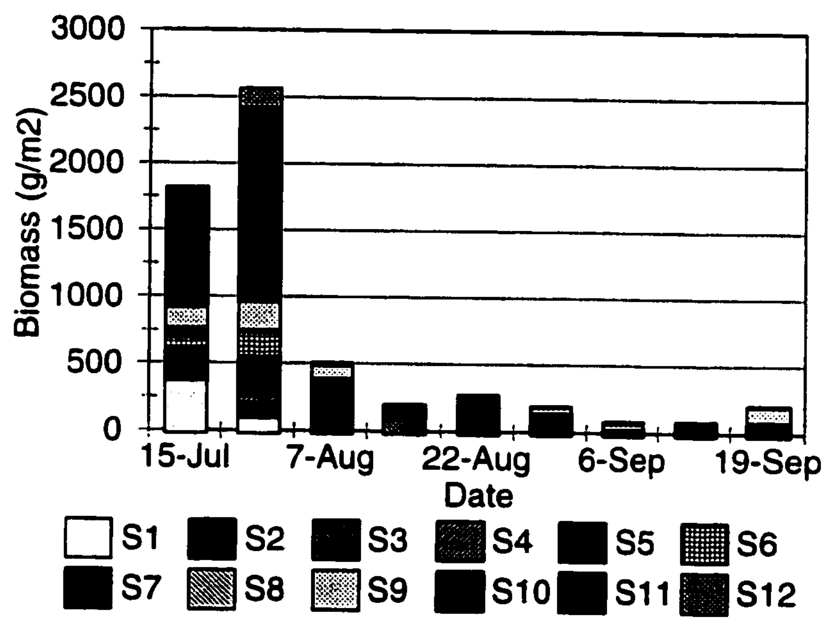
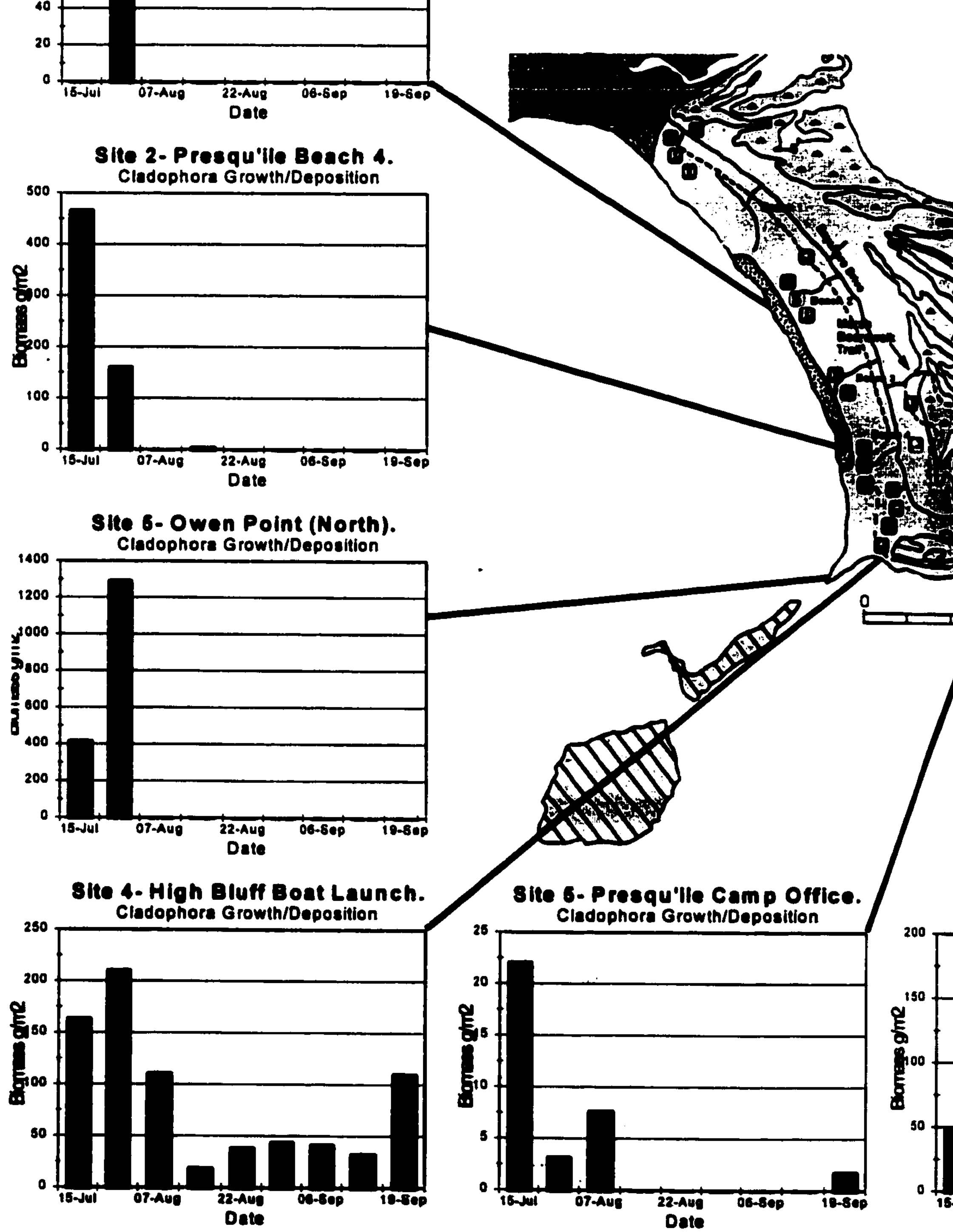
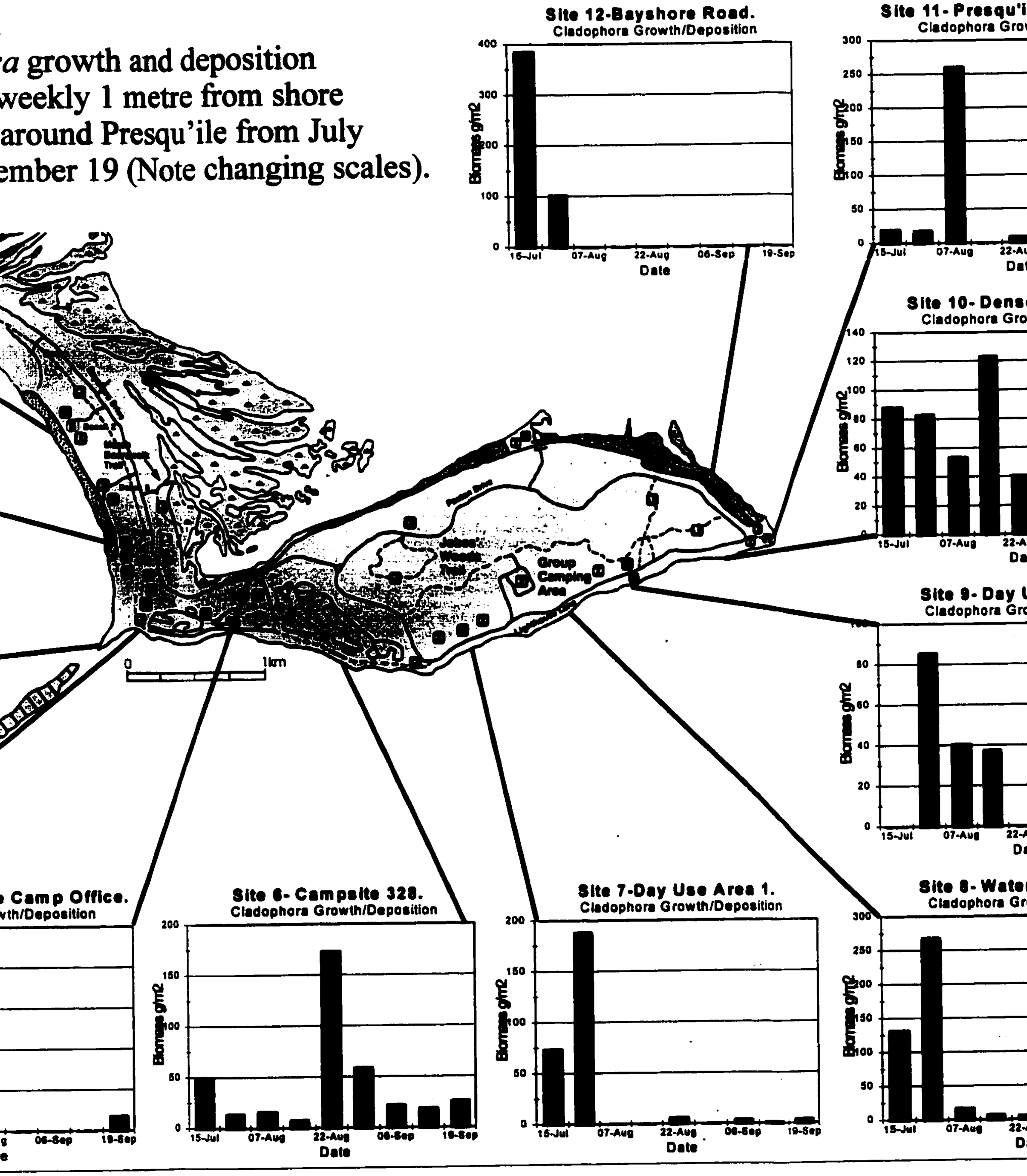


Figure 4.5.
Total *Cladophora* growth and deposition by date from the 12 sites surrounding Presqu'ile Provincial Park.

Figure 4.4.
Cladophora growth and d
measured weekly 1 metre
at 12 sites around Presqu'
15 to September 19 (Note



a growth and deposition
weekly 1 metre from shore
around Presqu'ile from July
ember 19 (Note changing scales).



sition
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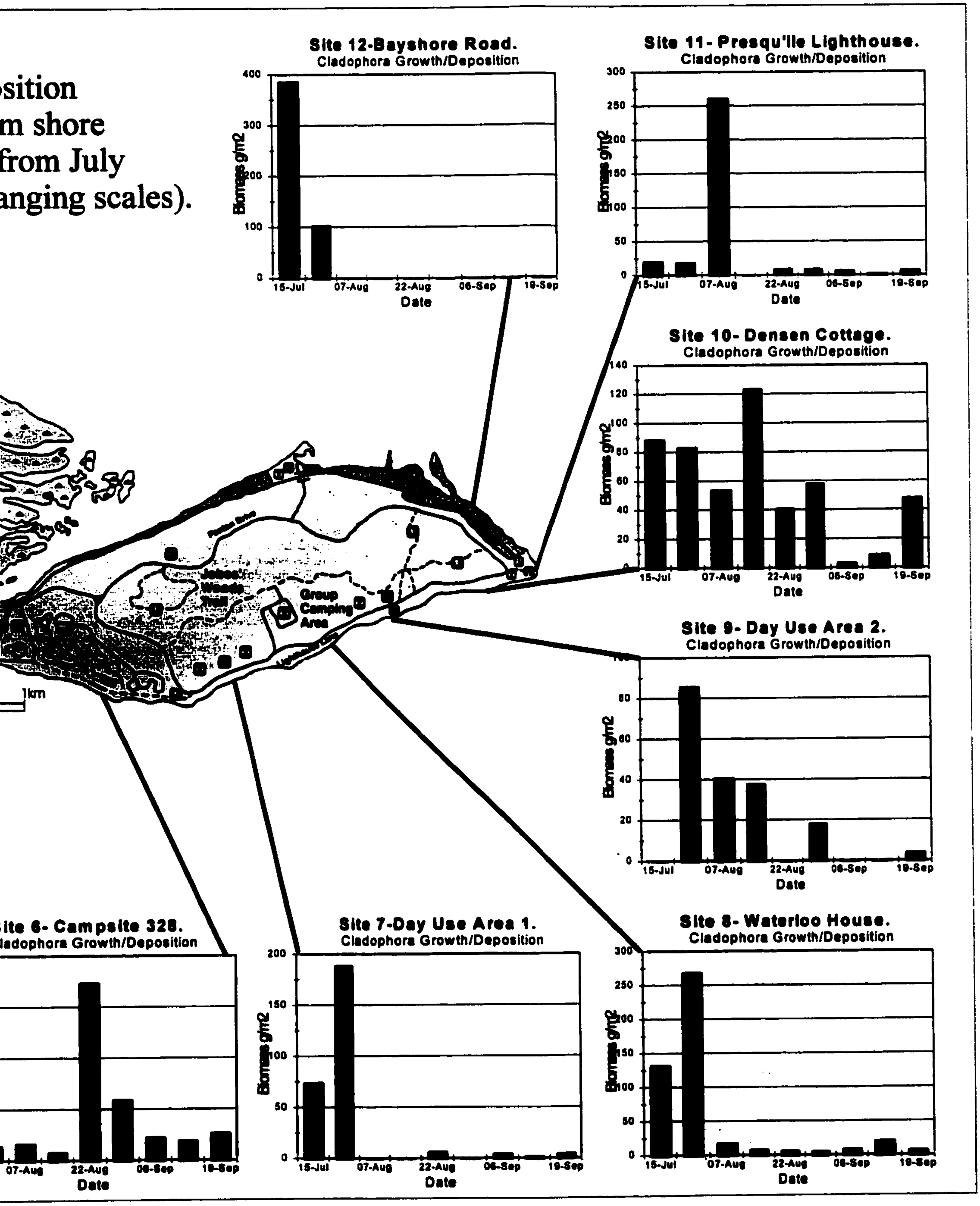

According to peak biomass measurements on the shoreline, maximum *Cladophora* growth around Presqu'ile occurred on or around July 23. This agrees with the peak date observed at the sample sites 1 and 2 at depths of 1.5, 4.6 and 9.1 metres.

Cladophora growth at the shoreline was not evenly distributed at the 12 sites over the study period (Fig. 4.6).

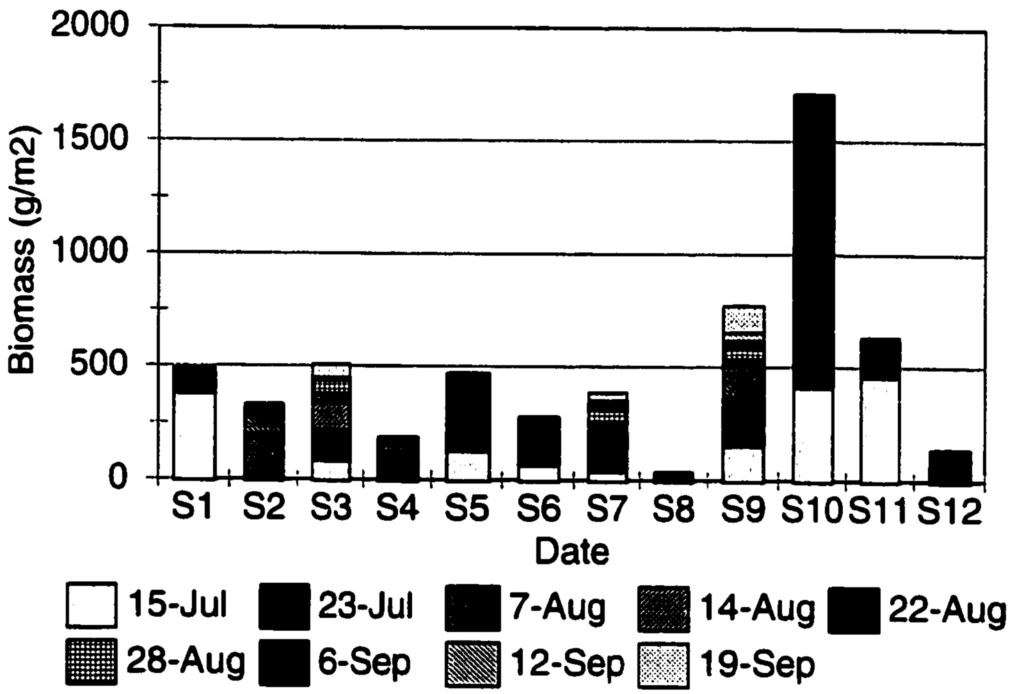

Fig. 4.6.
Cladophora growth and deposition by site for the entire growing season from July 15 to September 19.

For sites 1, 4, 5, 6, 9, 10, 11 and 12, deposition between July 15 and 23 accounts for the majority of total growth and deposition collected at the sites. These results can be attributed to the mid-summer *Cladophora* die-off when the algae was deposited on the shoreline. Maximum deposition occurred at sites 9, 10 and 11 where the sloughed

Cladophora was piled up to two metres out into the lake. The only time algae was collected from site 1 (beach 2) was during the mid-summer die-off. The site has a sand substrate and is totally unsuitable for *Cladophora* growth (Fig. 4.7).

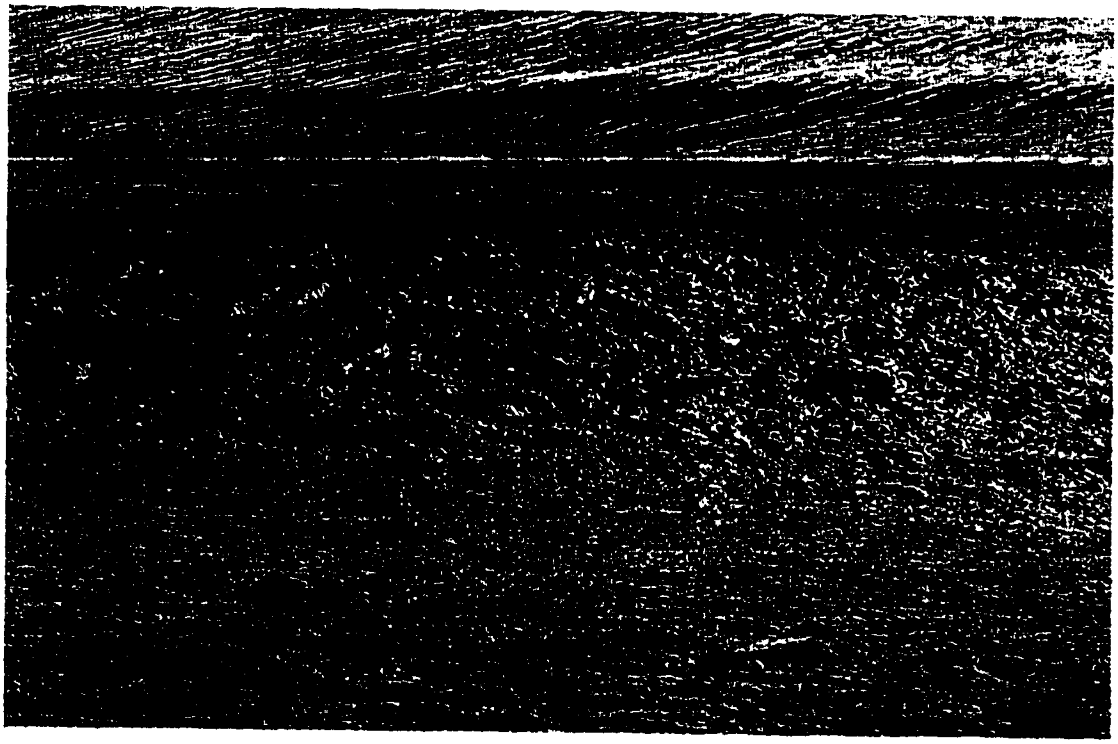

Figure 4.7.
Cladophora deposition at site 1 (Beach 2) on July 23, 1999.

Algae were also collected from the beach by maintenance crews while attempting to create a more aesthetically pleasing beach for park users. From June 15 to August 19 248 truckloads of *Cladophora* and sand were collected with the peak being July 22 when 30 loads were collected in one day (Fig. 4.8). Thirty truck loads equals 202 500 kilograms of *Cladophora* and sand removed from the beach in one day. The 55 loads of *Cladophora* collected on July 21,22 and 23 was more than twice as much as was collected over any other three day period in the summer of 1999. These data, in association with the information collected from the 12 sites around Presqu'ile and data from sites 1 and 2 offshore of the park, indicate that peak *Cladophora* biomass was reached around July 22.

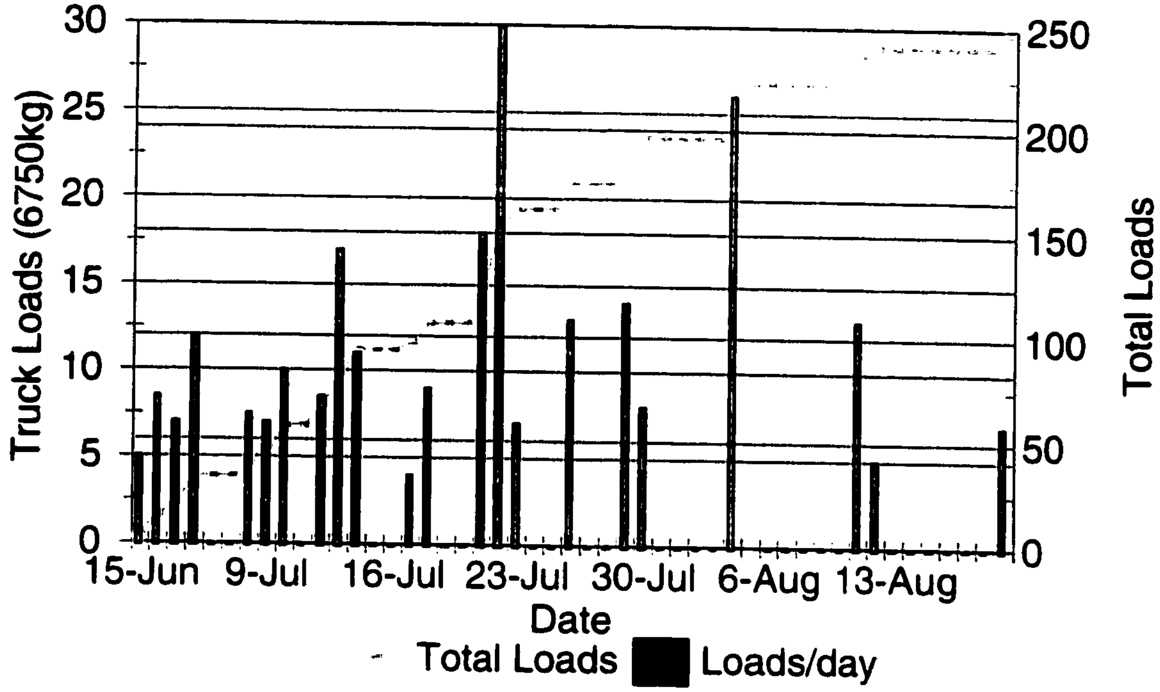

Figure 4.8.
Cladophora collected from the beach by maintenance crews from June 15 to August 19, 1999.

Analysis of the algae sand collected from the algae pile on August 25 indicates that on average, 4.9% of the material by dry weight is plant matter. The majority of the materials collected by maintenance crews is sand and sediment.

4.5 Zebra Mussels

Zebra mussels have been discussed in biomass (g/m^2) instead of numbers of individuals as done by Bailey et al., (1999) because of the difficulty and time-consuming nature of counting and measuring individuals.

The biomass (g/m^2) of zebra mussels at site 1 indicates a decline in the weight of mussels from June 11 to July 28 followed by a large increase on August 23 (see Fig. 4.9).

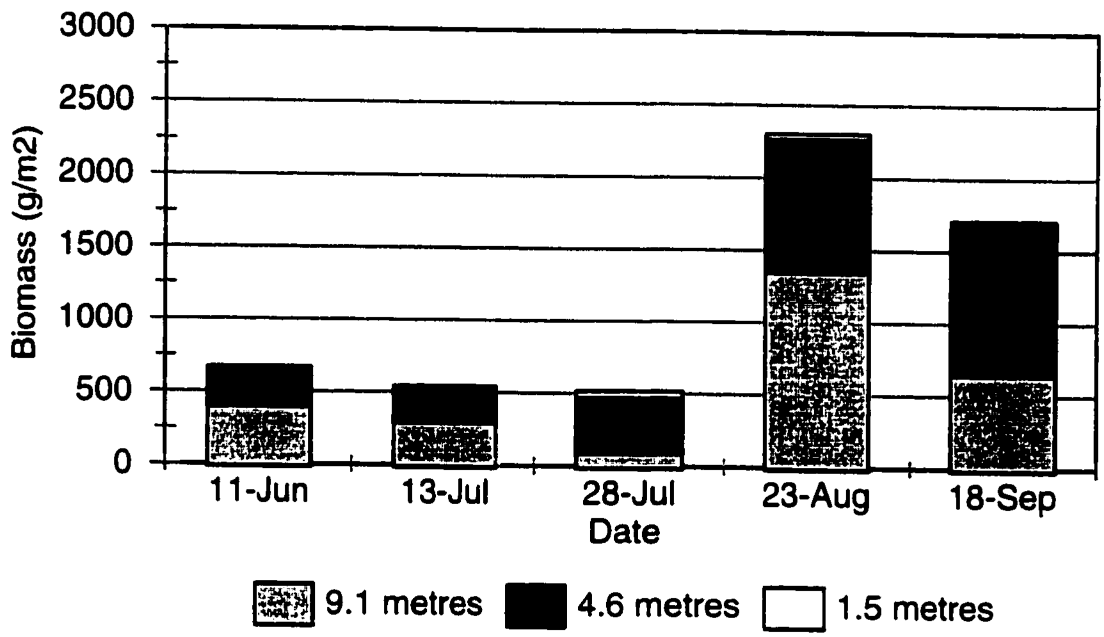

Figure 4.9.
Zebra Mussel biomass at site 1 from June 11 to September 18.

The declining trend from June 11 to July 28 is likely a result of sampling error. Early in the study season the focus was exclusively on attempting to collect all of the *Cladophora*, the zebra mussels being a secondary concern.

The data, although flawed, do indicate that the mussels prefer deeper depths. According to Bailey et al. (1999), this would indicate a high percentage of Quagga (*D.*

bugensis) mussels. However, visual examination of the dried Zebra Mussel samples found that the majority of the samples were Zebra Mussels (*D. polymorpha*).

Data from site 2 indicate an increase in mussel biomass from June 16 to August 23 followed by a slight decline on September 18. The decline can be explained by the disappearance of any mussels at a depth of 1.5 metres (Fig. 4.10).

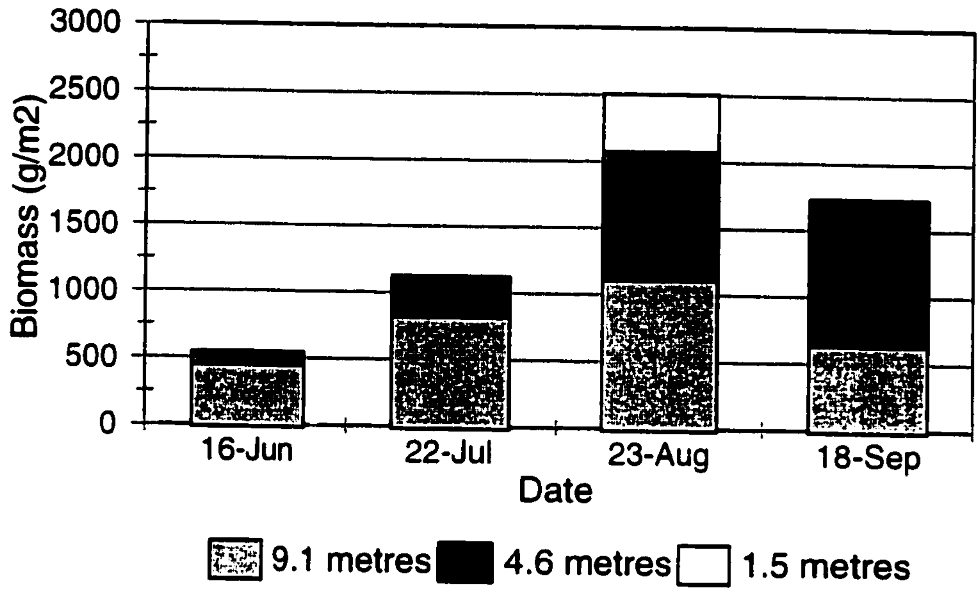

Figure 4.10.
Zebra Mussel biomass at site 2 from June 16 to September 18.

Late in August the frequency and magnitude of wind and storm events increase, resulting in the shallow water mussels being sheared off the lake bottom (Brebner and LeMéhauté, 1958).

4.6 Aquatic Invertebrates

The scuds collected from site 1 and at site 2 show different trends. Over the study period at site 1, more scuds were found at a depth of 4.6 metres than all other depths combined (Table 4.6).

Table 4.6.
The number of scuds at site 1 per m².

	4-Jun	11-Jun	13-Jul	28-Jul	23-Aug	18-Sep	Total
1.5 metres	NS	0	152	8	20	NS	180
4.6 metres	20	NS	8	4	24	1132	1188
9.1 metres	20	200	0	112	124	168	624
Total	40	200	160	124	168	1300	1992

NS- No Sample

The data are skewed by the sample collected at 4.6 metres on September 18. Without the 1132 scuds per m² collected then, only 56 scuds would have been found at the depth of 4.6 metres over the duration of the study.

At site 1 the scuds do show a trend in declining in numbers as *Cladophora* biomass increases until July 28. The peak of *Cladophora* biomass in mid to late July at site 1 corresponds with the lowest number of scuds found. This may partially be a result of the scuds not being separated from the sample because of the bulk of material being handled. The quantity of scuds found begins to increase again in August until it peaks in early September.

At site 2, 1636 scuds were collected in the four sampling dates, 356 less than collected in the six sample dates at site 1. No more than 41% of the total number of scuds at site 2 were collected at one time while 57% of the total number of scuds were collected on September 18 at 4.6 metres at site 1 (Table 4.7).

Table 4.7.
The number of scuds at site 2 per m².

	16-Jun	22-Jul	23-Aug	18-Sep	Total
1.5 metres	NS	672	176	NS	848
4.6 metres	272	12	0	384	668
9.1 metres	0	20	8	92	120
Total	272	704	184	476	1636

NS- no sample collected

At site 2, the number of scuds increased with *Cladophora* biomass from June to July then declined significantly in August followed by an increase in September. The greatest numbers of scuds are found at a depth of 1.5 metres and numbers decline with depth in July and September. This trend exists despite the absence of any data from two of the four sample sites, there would be a stronger relationship if more samples were taken.

Scuds were also collected and separated from the shoreline algae samples. The results indicate that the maximum number of scuds occurred around July 22, the same time as peak *Cladophora* biomass (see Fig. 4.11). These results are strongly influenced by single sites with large numbers of scuds. At site 9 (Day use area 2), 3152 scuds per m² occurred at the peak of *Cladophora* biomass on July 22. These scuds at site 9 accounted for 73% of the total number of scuds deposited at the twelve sites monitored around the park on July 22. On August 7, 2608 scuds per m² occurred at site 2 (beach 4), accounting for 75.5% of the total number of scuds deposited around the park. On September 12, scuds deposited at site 7 (Day use area 1) accounted for 90.5% of the total number of scuds deposited around the park. These large localized populations are found at several sites around the park at different times. There is no clear pattern with regard to the number of scuds that are observed, but generally speaking the sites had some scuds present for the duration of the study period or none at all.

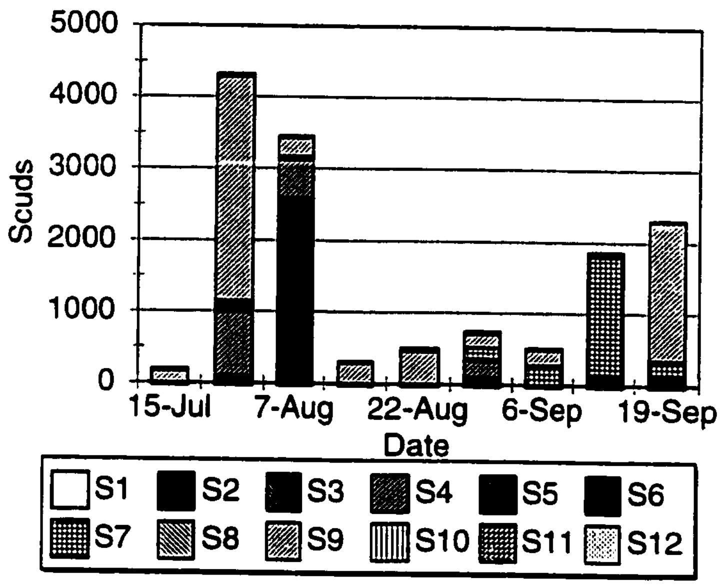

Figure 4.11.
The total number of scuds collected in shoreline samples by date.

Caddisfly larvae were present in the samples in far lower numbers than the scuds. At site 1, 116 Caddisfly larvae was collected over the entire study period (Table 4.8).

Table 4.8.
The number of Caddisflies at site 1 per m².

	4-Jun	11-Jun	13-Jul	28-Jul	23-Aug	18-Sep	Total
1.5 metres	NS	0	0	0	0	NS	0
4.6 metres	0	NS	4	0	4	16	24
9.1 metres	0	28	0	16	20	28	92
Total	0	28	4	16	24	44	116

NS- no sample collected

The largest number of Caddisfly larvae were collected at the beginning and the end of the study season at site 1. At Site 2, the maximum number of Caddisfly larvae were found at the peak of *Cladophora* growth, July 22 (Table 4.9).

Table 4.9.
The number of Caddisflies at site 2 per m^2.

	16-Jun	22-Jul	23-Aug	18-Sep	Total
1.5 metres	NS	4	0	NS	4
4.6 metres	16	12	8	20	56
9.1 metres	0	68	16	0	84
Total	16	84	24	20	144

NS- no sample collected

The Caddisfly larvae numbers were lower in mid-summer at site 1 likely because of the presence of sand that drifted into the area and covered large portions of the substrate. Although the occurrence of Caddisfly larvae was at different times of year at the two study sites, the depth distribution of these invertebrates was similar. At both sites the largest number of Caddisfly larvae occurred at 9.1 metres. No larvae were found at 1.5 metres at site 1 and only 4 were found at 1.5 metres at site 2 over the entire study period.

Caddisfly larvae were also observed three times in the shoreline samples (see Table 4.10).

Table 4.10.
Caddisfly larvae from shoreline sample sites.

Date	Site	Number of Larvae per m^2
July 23	6	144
August 7	5	16
August 28	2	16

Site 6 is located between the dive sites 1 (Densen) and 2 (High Bluff Island). The number of larvae per m^2 (144) found at this site are equal to the total number collected from dive site 2.

Bloodworms were also found in samples collected on June 16 in 1.5 metres of water between sites 1 and 2 (1a). These invertebrates were in very low numbers and are destroyed in the drying process so were excluded from this study. A crayfish was also inadvertently collected in a June 11 sample in 9.1 metres of water at site 1.

4.7 Statistics

Statistics were done on samples where relationships were suspected or appeared to be related. The results of tests are summarized in the following table (Table 4.11).

Table 4.11.
Results of the linear regression tests

Test	Variables	r^2	Sig.
Linear Regression	Zebra mussel biomass Total Nitrogen	0.85	0.05

4.8 Summary

The results of this study indicate that Lake Ontario conditions and water chemistry are suitable for *Cladophora* growth. Peak *Cladophora* biomass occurred on July 22, 1999 and was followed by a rapid decline. Zebra mussels reached their maximum biomass on August 23, although sampling error may have influenced this date. All of the results will be discussed in detail in the following chapter.

Chapter 5

Discussion and Summary

5.1 Site Selection, the duration of the study and when sampling occurred

This study is different from other studies on *Cladophora* because it examines growth at depths down to 9.1 metres. Traditionally studies on filamentous algae occur at depths of only 3 metres and less (Lorenz and Herdendorf, 1982; Neil and Jackson, 1982; Millner et al., 1982). It was important to include deeper depths in this study because of the increased clarity of Lake Ontario in the nearshore zone (1-15 m) since the introduction of zebra mussels (Bailey et al., 1999).

One of the goals of the study was to examine *Cladophora* to a depth of 10 metres. Unfortunately crude depth gauges that gave measurements in feet resulted in the deepest depth being 9.1 metres instead of the 10 metres that was planned. Ten metres is a critical depth because it is regarded as the fair weather wave base. The most common waves, those with a 4- to 5-second period work sediments at depths of up to 10 metres deep (Brebner and LeMéhauté, 1958). Under normal *Cladophora* growth conditions, even fair weather waves can result in increased sloughing and deposition on shoreline. During larger events, waves of between 2 and 3 metres in height can work sediments 20 metres below the surface. These events result in large quantities of *Cladophora* being stripped from the bottom (Blum, 1982). One possibility to improve this study would be to sample to the depth where *Cladophora* growth stops.

One factor that was not considered during the study period was the impact of changing Lake Ontario water levels. According to data from the Cape Vincent, New York lake monitoring station, the lake levels rose in the early summer then declined by September (Table 5.1).

Table 5.1.
Water Levels in Lake Ontario at Cape Vincent, New York between June and September, 1999.

Month	Water Level (metres)
June	74.766
July	74.813
August	74.713
September	74.567

source: www.co-ops.nos.noaa.gov/cgi-bin/co-ops_qry.cgi

The total change in Lake Ontario water level from maximum to minimum was 24.6 centimetres. Over half of this decline occurred from August to September when lake levels dropped 14.6 centimetres. Because of the inaccuracies of up to 20 m that exist in the GPS technology used to locate the study sites and the depth of the study sites used, the variation in the water levels had little if any impact on the accuracy of the *Cladophora* data collected for this study.

Field research began in early June once SCUBA certification was completed. Water temperature at the time of the first dive was 7.9°C, at the lower limits of where *Cladophora* growth begins. Growth was first detected at this time in cracks and fissures on the lake bottom. Blum (1982) and Lorenz and Herdendorf (1982) also observed this pattern of distribution early in the season. SCUBA sampling continued until mid-September when very little *Cladophora* growth was measured and a research assistant was no longer available. Sampling should have continued since *Cladophora* occasionally has a second growth recorded as late as October (Wong et al., 1978).

SCUBA sampling was originally planned to occur every two weeks at each of the study sites, but did not because of employment commitments, equipment problems and difficult lake conditions. Because of the weak stomachs of the research assistants and because the small boat was unsafe for rough water, sampling could occur only when there was no wind and wave height was less than 0.5 metres. This narrow range of climatic conditions when sampling occurred has possibly influenced some of the results.

5.2 The accuracy of the suitable site analysis

The suitable site analysis used to select the study sites was reasonably accurate. Both sites selected with the model experienced significant *Cladophora* growth. At site 1, more growth was measured at deeper sites, the opposite of the model's prediction. This is likely because of the impact of wave action, which can strip *Cladophora* from the substrate and was not included in the model (Auer et al., 1982c). Maximum growth at site 2 occurred in 1.5 metres of water and decreased with depth as predicted. It was not stripped from the substrate by wave action because it was not as nutrient limited, and the healthy *Cladophora* was more resistant to sloughing. Nutrients in the water and their effect on the *Cladophora* will be discussed later in sections 5.3 and 5.4.

The suitable site analysis predicted similar levels of growth at the two dive sites. On average, Site 2 produced 10 g/m^2 more *Cladophora* per sample than Site 1. This small difference can be attributed to the fact that Site 1 was not sampled on July 22. Peak biomass is predicted on July 22 and site 2 produced 243.12 g/m^2 at this time, 1.6 times the quantity produced at maximum biomass at site 1 on July 28.

A problem with the suitable site analysis was the dynamic nature of sand in the Presqu'ile area. The map used for the lake substrate (Rukavina, 1970) was dated and could have indicated significant *Cladophora* growth in areas now covered by sand. At Site 1, from the beginning of the study in June to the third sampling date in late July, up to 10 centimetres of sand had drifted into the site. The sand covered the algae and stopped growth in certain areas. Fortunately the sand did not completely cover the area and had drifted away by August so *Cladophora* samples could still be collected.

5.3 Physical conditions and chemistry of Lake Ontario

In early June, Lake Ontario was thermally stratified and limited growth was observed. A relationship has been documented in other studies between *Cladophora* growth and temperature (Whitton, 1970). This relationship was not observed in this study due to the small sample size. However, the maximum water temperature does occur at peak biomass and when maximum sloughing was recorded. In rivers, *Cladophora* populations were observed to completely disappear in five days because of rising water temperature and to remain absent for the following ten days (Wong et al., 1978). Although other factors such as nutrient limitation can play a role in the mid-summer *Cladophora* die-off, water temperature is the major factor in the sloughing of *Cladophora* and beach fouling at Presqu'ile Park.

Bailey et al. (1999) indicated that Lake Ontario water clarity in the nearshore zone is improving because of the impact of zebra mussels. Secchi depth is not considered to be a limiting factor to *Cladophora* growth in the area since Secchi disk transparency generally exceeds the depth of the sample site (Millner et al., 1982). Secchi depths are not completely representative of water clarity at the sites because of the fact that sampling occurred only when there was minimal wave action to stir up sediments (Neil and Jackson, 1982).

No clear relationship was observed between Lake Ontario pH and *Cladophora* biomass or water temperature. pH remained within the acceptable limits for *Cladophora* for the duration of the study period and averages 8.2, the level at which optimum growth occurs (Whitton, 1970). No clear relationship was observed between conductivity and pH, *Cladophora* biomass or water temperature either. Conductivity at the sites showed very little variability, with the exception of the July 13 sample at Site 1. July 13 was the roughest day sampling occurred, with moderate winds and waves up to approximately 50 centimetres which may have stirring the bottom sediments. These conditions resulted in the water being more turbid than usual and stirred the sediments into the water column.

Current speed and wind direction were also measured, but the measurements are biased. Sampling only occurred under calm conditions with very little wind and wave action and there were only 13 samples. Also, the conditions recorded are not representative of all the conditions found in eastern Lake Ontario. However, the results indicate that in general, westerly winds are associated with a higher current velocity. This is related to increased fetch distance.

Water chemistry was variable between the two dive sites, particularly with regard to phosphorus and nitrogen. Total phosphorus (TP) at Site 1 was low, averaging 0.0056 mg/L over the study period and peaking at 0.01 mg/L on August 23. These levels are significantly below the 0.03 mg/L required for significant *Cladophora* growth (Shear and Konasewich, 1975).

TP levels measured at Site 2 averaged 0.039 mg/L with a peak of 0.092 on September 18. TP levels at site 2 rose through the study season and can be related to two factors. The first is the bird population on the islands near the study site. This colony produces more waste as the season progresses and chicks grow. The bird colony and its impact will be discussed in detail later in section 5.8. The second explanation for rising TP levels is that when water temperatures peak in late July and *Cladophora* sloughing begins to occur, phosphorus uptake rates decline (Auer and Canale, 1982b).

Mean summer epilimnetic TP levels were measured in Lake Ontario in 1982 and were 0.014 mg/L (Stevens and Neilson, 1987). TP data collected at 10 locations other than Site 2 during this study averaged 0.0056 mg/L and indicate that in general, TP levels are declining. It is important to be cautious when comparing the data since the research by Stevens and Neilson (1987) was conducted in the offshore zone. However since nutrient levels tend to be higher at nearshore point source locations, it can be used to show a general decline in TP levels (Neil and Jackson, 1982).

In Chapter 2 it was discussed that phosphorus has more impact on *Cladophora* growth than any other nutrient (Canale and Auer, 1982b). At Presqu'ile, nitrogen also plays a major role in *Cladophora* growth. Nitrogen to phosphorus (NO_2,NO_3::TP= N:P) ratios are used to determine the nutrient that algae is limited by. Once the N:P ratio is below 20:1, *Cladophora* becomes nitrogen limited (Stevens and Neilson, 1987). In 1982, the mean Lake Ontario N:P ratio was greater than 35:1 and had risen from a level of 16:1 in 1972 (Fig 2.10). Total Kjeldahl Nitrogen (TKN) levels are not included in the N:P ratio and remained stable or rose slightly over the study period.

Over the study period, the average N:P ratio at site 1 was highly variable and averaged 47:1 (Table 5.2).

Table 5.2.
N:P ratios at Site 1 (Densen Cottage).

Date	N:P
June 11	83:1
July 13	72:1
July 28	64:1
August 23	8:1
September 18	54:1
Average	47:1

On average, N:P ratios have continued to grow since 1982 as phosphorus inputs into the Great Lakes have continued to be minimized. The N:P ratio at Site 1 on August 23 resembled pre 1972 levels and *Cladophora* growth was limited by a nitrogen shortage (Stevens and Neilson, 1987). Site 2 also had its lowest N:P ratio August 23 (Table 5.3).

Table 5.3.
N:P ratios at Site 2 (High Bluff Island)

Date	N:P
June 16	10:1
July 22	11:1
August 23	1.6:1
September 18	2.2:1
Average	13.7:1

Cladophora at Site 2 was nitrogen limited for the duration of the study. The limitation is related to a combination of increased TP available for growth and nitrogen levels that decline over the study period. The generally declining nitrogen and N:P levels over the study season have also been observed by Neil and Jackson (1982). The low measurements for N on August 23 at both sites do not appear to be related to temperature, pH, conductivity, *Cladophora* or aquatic invertebrates. However, they do correspond with maximum zebra mussel biomass and will be discussed later in section 5.6.

5.4 *Cladophora* Samples

Cladophora growth at Presqu'ile Provincial Park was measured in 1972, 1982 and 1983 by Painter and Kamaitis (1987). From 1972 to 1983 growth declined in the area by approximately 77%. From 1983 to 1999, *Cladophora* growth increased by 4.8% (Fig. 5.1).

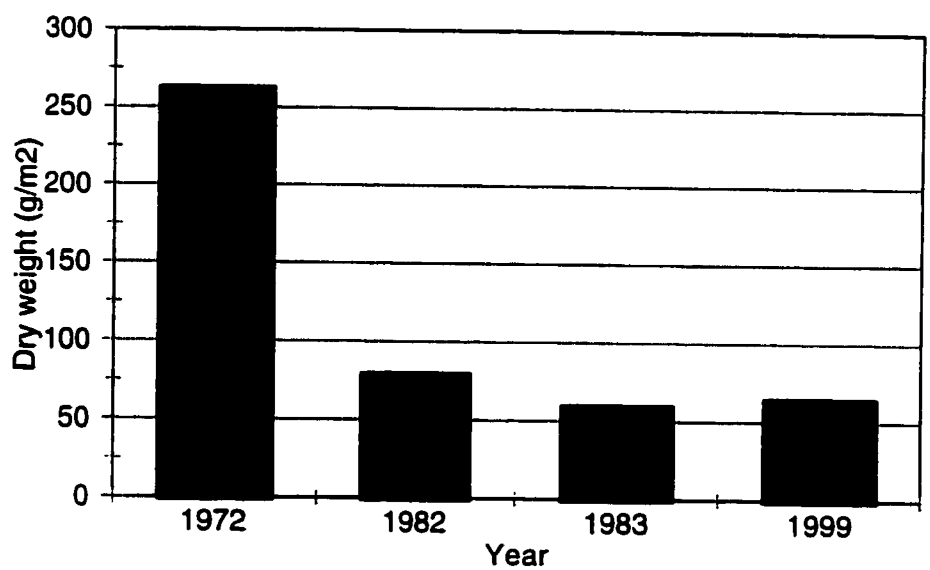

Figure 5.1.
Cladophora growth at Presqu'ile Park from 1972 to 1999 (Painter and Kamaitis, 1987).

The small increase in growth measured from 1983 to 1999 is likely because of differences in sampling dates, depths and sample site location. Sampling dates for the two studies are summarized in Table 5.4.

Table 5.4.
Sampling dates of Painter and Kamaitis (1987) and this study. "X" indicates no data collected.

Painter and Kamaitis, 1972	Painter and Kamaitis, 1982	Painter and Kamaitis, 1983	Study
June 4-6	X	June 8-15	June 11-16
July 5-12	July 6-14	June 21-29	July 13-16
August 5-10	X	July 5-13	July 22-28
X	X	X	August 23

Samples were collected by Painter and Kamaitis (1987) at four depths with a maximum of 5 metres. Samples for this study were collected at depths up to 9.1 metres because of the increased clarity of Lake Ontario caused by zebra mussels.

Painter and Kamaitis (1987) collected samples from the area described in this study as Site 1a. The average used to compare algae growth in the area to Painter and Kamaitis (1987) included Sites 1, 1a and 2. Growth at site 1a was collected only on 2 occasions, but average *Cladophora* biomass was 61.1 g/m^2. Despite the differences in sampling dates, depths and site location, the data indicate that *Cladophora* growth in the Presqu'ile area is similar to early 1980s levels.

There are several reasons that *Cladophora* has become more of an issue with beach users and park management in the past five years. The first is that deposition on the Park's shoreline has increased since the early 1990s (pers. obs). The second is that the timing of peak biomass has changed. In 1983 *Cladophora* was sampled at Presqu'ile from July 5-13 to observe peak summer biomass (Painter and Kamaitis, 1987). In 1999 peak summer biomass was observed July 22. Maximum biomass and sloughing now occur when the Park is entering the busiest portion of the summer, the last week of July and the first in August. The third is that *Cladophora* deposition occurs at several high profile sections of the Park. Shoreline samples indicate that deposition at Beach 4 can be measured in metres while large quantities of algae wash into the campground area and result in an unpleasant odour up to a kilometre away (pers. obs.). The day use and lighthouse area shoreline is frequently fouled by *Cladophora* for park users to witness. Although there is more *Cladophora* present in the Presqu'ile area compared to recent memories, the quantities are well below historical highs.

The results found in this study with regards to *Cladophora* biomass must be approached cautiously. *Cladophora* biomass is subject to enormous spacial and temporal variations. Peak biomass can quickly decline in the event of a die off (Whitton, 1970) or in the event of a storm event with large waves (Blum, 1982). Small changes in biomass are likely due to sampling timing and antecedent conditions.

Despite the relatively low quantities of *Cladophora* compared to 1972, average tissue phosphorus levels are higher than recorded in 1972 (Painter and Kamaitis, 1987). This reinforces the water chemistry data, which indicated that *Cladophora* is not phosphorus limited at Presqu'ile. Unfortunately, tissue nitrogen levels were not determined to indicate if the *Cladophora* was nitrogen limited (Healey, 1978).

5.5 Algae/Sand Collected by Maintenance

Park maintenance crews collected algae from the beach from June to August and deposited it in a large pile at Beach 3. Unfortunately the value of the data it could provide was not realized until the collection of algae from the beaches had stopped. Samples should have been collected from the algae dump throughout the study period instead of just on August 25.

The organic material found in the algae sand ranged from 3-9% with an average of 4.9%. By weight, there is very little *Cladophora* in the materials collected from the shoreline by Park maintenance crews. It can be extrapolated that only 82 026 kg of the 1 674 000 kg collected by maintenance crews over the duration of the study period was algae. The remaining 1 591 974 kg of materials collected and moved is sand and water, not plant matter. For comparison, a *Cladophora* sample collected from Site 1 at 9.1 metres in Lake Ontario has 52.2% organic materials. The inorganic materials are sand and sediments trapped in *Cladophora's* filamentous branches. The methods used to collect algae from the beaches at Presqu'ile will be discussed in more detail in Chapter 6.

5.6 Zebra Mussels

Zebra mussels have improved water clarity in the nearshore region of Lake Ontario (Chase and Bailey, 1999). With increased water clarity, *Cladophora* now grows at deeper depths and this can have an impact on shoreline fouling. Although no significant increase in biomass per metre^2 was measured between 1983 and 1999, there is now more area for the *Cladophora* to grow on because of increased light intensity at the lake bottom at deeper depths. The low slope of the Lake Ontario bottom results in even a small increase in water clarity resulting in a large area of substrate being opened for *Cladophora* growth (Fig 5.2).

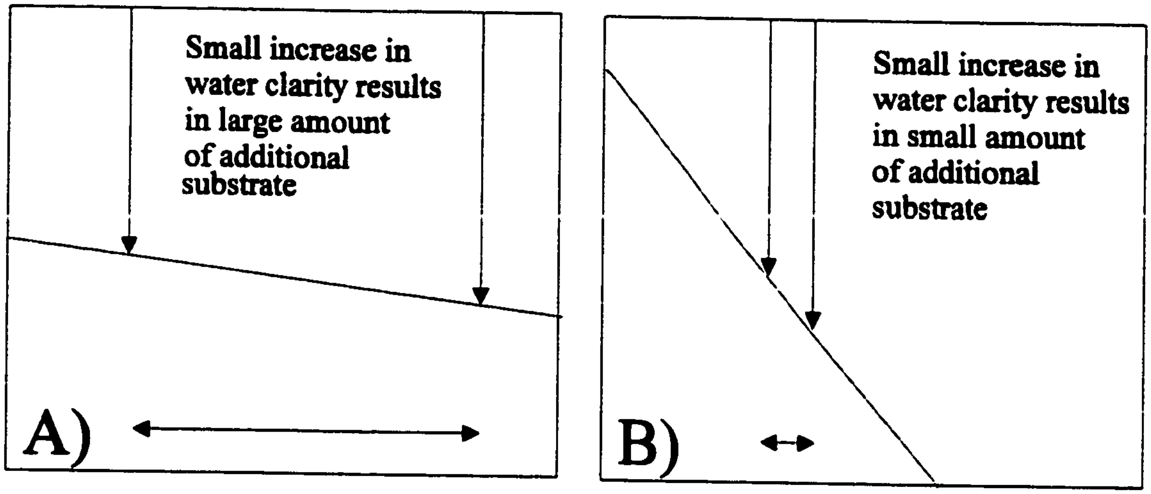

Figure 5.2.
A) Impact of increased water clarity on a gradual slope such as seen in Lake Ontario. A large quantity of substrate is exposed for *Cladophora* growth with a small light increase.
B) Impact of increased water clarity on a steep slope, very little increase in substrate exposed for *Cladophora* growth.

Zebra mussels also have an impact on nutrients in the water. Although the sample size was small (10), there was a strong correlation (r^2=0.85) between total Nitrogen (NO2,NO3,NH3) levels and zebra mussel biomass. The relationship between zebra mussels and nutrients is poorly understood. What is known is that phosphorus and nitrogen have a higher absorption rate with smaller particles (Hwang et al., 1976). These small particles have a higher surface area and are preferentially selected by zebra mussels of all sizes (Makarewicz et al., 1999). When ingested, the nutrients are moved from the water column to the lake substrate where zebra mussels and *Cladophora* reside.

5.7 Aquatic Invertebrates

Examination of the aquatic invertebrate data and *Cladophora* biomass indicated no clear relationship. It was expected that more algae would result in more invertebrates since more epiphytes would become trapped in *Cladophora's* filamentous branches (Rosen et al., 1981). The findings are similar to those of Harrison and Hildrew (1998), who also found no correspondence between algal and invertebrate biomass.

The higher number of invertebrates in the fall corresponds with shorebird migration. When the *Cladophora* is sheared from the bottom by wave action the algae and invertebrates are washed ashore. They are quickly consumed by shorebirds, of which there are 16 common species found at the park (Pomeroy, 1999).

5.8 The Bird Colony

A strong correlation (r^2=0.61) exists between bird biomass and TP concentrations (Hoyer and Canfield, 1994). A colony of 250,000 colonial water birds lives on Gull and High Bluff Islands off Presqu'ile. Gull droppings are a known source of phosphorus, which is required for extensive *Cladophora* growth (Auer and Canale, 1982a; Hartig and Gannon, 1986). Gull and High Bluff Island are dominated by two species, Ring-billed Gulls (*Larus delawarensis*) and Double-crested Cormorants (*Phalacrocorax auritus*). The Ring-billed Gull colony at Presqu'ile is the largest in eastern Lake Ontario and the population peaked in 1990 at 69417 nests (Canadian Wildlife Service, 1999). Although the Ring-billed Gull population peaked in 1990, the quantity of *Cladophora* being deposited on the beach did not begin to rise at that time. If bird excrement is a factor in the increased *Cladophora* growth, it is likely related to the Double-crested

Cormorant. Cormorant numbers have risen exponentially since the first nesting pair since the 1960's arrived at the park in 1982 (Fig. 5.3.).

Although the total number of Ring-billed Gull and Double-crested Cormorant nests declined by 5367 birds between 1990 and 1999, the biomass increased because of changing species composition (Canadian Wildlife Service, 1999; LaForest, 1991). A cormorant's average weight is 2.3 kilograms while a Ring-billed Gull weighs only 0.7 kilograms (CWS, 2000; Johnsgard, 1993). Table 5.5 shows Cormorant and Ring-billed Gull biomass on Gull and High Bluff Islands from 1976-1999.

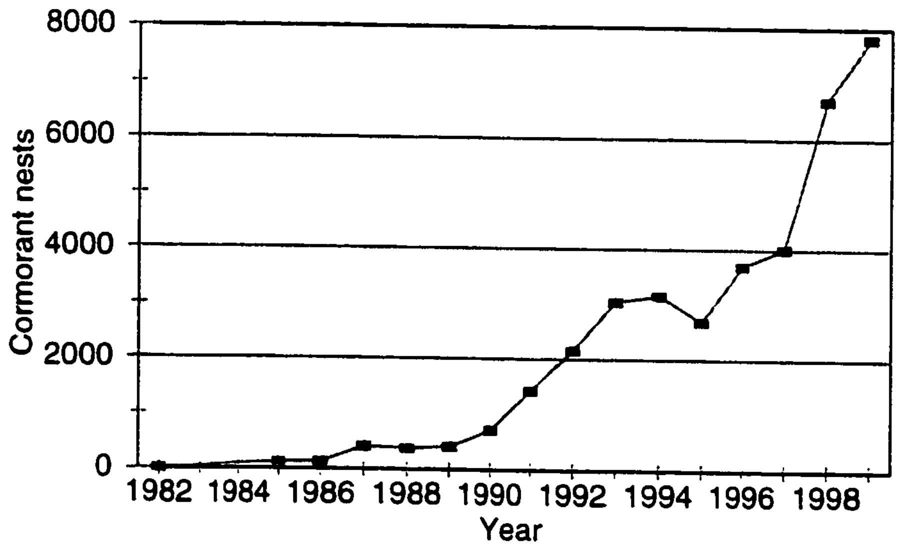

Figure 5.3.
The number of Double-Crested Cormorant nests at Presqu'ile Provincial Park between 1982 and 1999 (Canadian Wildlife Service, 1999; LaForest, 1991).

The bird biomass from Gull and High Bluff Islands is a conservative estimate. It does not include non-nesting birds or species such as Herring Gulls, Great Black Back Gulls and Black-crowned Night Herons, which also nest there, albeit in small numbers.

Table 5.5.
Double-crested Cormorant and Gull Biomass (kg) on Gull and High Bluff Islands from 1976-1999 (Canadian Wildlife Service, 1999; CWS, 2000; Johnsgard, 1993; LaForest, 1991).

Year	Ring-Billed Gulls	Double-crested Cormorants	Total Birds	Total Biomass
1976	23707	0	23707	16594.9
1990	69417	1592	71009	52253.5
1999	57699	7815	65514	58363.8

The bird excrement from Gull and High Bluff Islands provides nutrients for *Cladophora* growth (Goulden et al., 1970). Birds can significantly contribute to nutrient loading, especially if large populations of birds feed outside of the area in which they roost (Hoyer and Canfield, 1994). Great Lakes cormorants tend to forage within 10 kilometres of their breeding colony, but can travel as far as 40 kilometres (Neuman et al, 1997). Presqu'ile Cormorants have been seen feed as far away as the Bay of Quinte.

Summary

The primary reason for increased *Cladophora* growth and deposition around Presqu'ile Provincial Park in the past decade is an increase in water clarity, which has resulted in more suitable sites for growth. Although bird biomass in the area has increased and resulted in nutrient enrichment at the High Bluff dive site, *Cladophora* biomass per metre^2 remains similar to early 1980s levels. The increase in *Cladophora* at Presqu'ile Provincial Park can be attributed to zebra mussel colonization of the area and increased water clarity in the nearshore zone.

Chapter 6

Recommendations and Future Research

6.1 Recommendations for beach management at Presqu'ile Park

Presqu'ile Provincial Park needs to question current beach management practices. It is unlikely that *Cladophora* deposition around the Park will significantly decline even if the colonial water bird population disappeared or human nutrient inputs into Lake Ontario were reduced. Because of the invasion of zebra mussels, there is now more habitat available to filamentous algae such as *Cladophora* (Fig 5.2). Minimal algal growth, even under nutrient limited conditions, will result in some beach fouling. The recommendations based on this study are as follows:

1) If algae collection from the shoreline continues to occur, Presqu'ile needs to:

- Focus its attention on the north end of the beach, specifically beaches 1 and 2. This portion of the beach experiences the least algal deposition and is currently the most popular with day use visitors. It is also where the snack bar is located.
- Stop advertising Beach 4 as a swimming beach. Instead use the area for parking and as a staging area for the Owen Point Trail. Beach 4 often has the largest accumulations of algae deposited on the shoreline and recent attempts to deal with the problem, including flagging the area have been unsuccessful.

- Stop raking beach 4 and let it regenerate. The naturalized portion of the beach would be ideal for birds and bird watchers and would require very little management.
- Improve the Bike Trail that connects the campgrounds to the beaches. The section between the Park store and Beach 2 is gravel and young children find it difficult to cycle. By improving access to Beaches 1 and 2, people will use the more aesthetically pleasing facilities and have a higher opinion of the park.

2) The techniques used to collect the algae also need to be examined. Current practices are essentially mining the beach, an illegal practice under Ontario Parks policy. If the algae/sand continues to be collected from the beaches throughout the summer, it should be:

- Spread again in the littoral zone in early September. The algae stored on the beach will not begin to grow if returned to the lake and the nutrient inputs associated with it are likely insignificant when compared to the nutrient inputs made by the bird colony on Gull and High Bluff Islands.
- Store the algae sand in one location on the beach. By selecting one location and piling the collected *Cladophora* and sand there every year, the park will minimize its impact on the surrounding vegetation and dune system.
- Current algae collection practices should be viewed as a temporary solution. Presqu'ile must investigate new algae removal techniques that result in more *Cladophora* and less sand and water being collected (Fig 6.1).

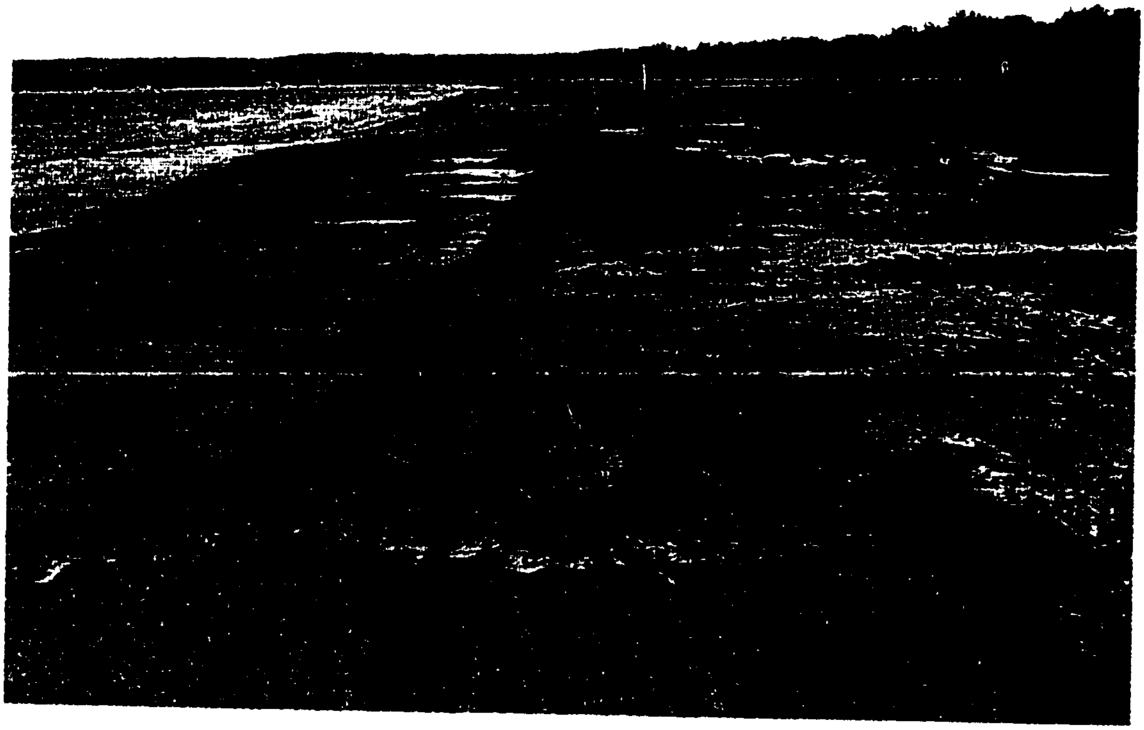

Figure 6.1.

Cladophora/sand piles removed from the water to be collected by park maintenance crews.

Cladophora deposition on the beach at Presqu'ile Provincial Park is not a new phenomenon. Its history can be traced to the early 1950s and it will continue to occur. Park management needs to concentrate its attention on providing an aesthetically pleasing swimming beach for visitors and to do this, the Park should focus labour and resources on the north end of the beaches.

6.2 Future Research

Future research should focus on the role of zebra mussels in filtering out nutrients and depositing them near the bottom where *Cladophora* growth occurs. This will help determine the nature of the relationship between *Cladophora* and zebra mussels. Zebra mussel location and age distribution would also be beneficial to determine if the mussels are filtering the water too efficiently and potentially starving themselves. If another dive study of any kind is undertaken, an evaluation of light conditions would be beneficial to determine at what depth *Cladophora* in the region are light limited.

Quantifying the nutrient inputs made by the bird colony will help determine the role of bird biomass to *Cladophora* growth at Presqu'ile. Algae pile nutrient analysis would also be beneficial in order to quantify the annual inputs the park makes.

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